The wheat growth guide

Spring 2008, second edition

HGCA

Introduction

The wheat growth guide explains how wheat grows. The guide provides reference or 'benchmark' values for UK crops against which any grower, adviser, breeder, researcher or student can compare and interpret their own observations. Thus, the guide enables comparisons of crop progress to be made as an aid to husbandry.

The first edition, published in 1997, has been used widely. This second edition reflects changes in crop performance and increased knowledge over the past decade. In particular, a new section on rooting draws on recent HGCA-funded research.

Other HGCA publications, listed on page 30, provide more practical detail on manipulating growth through sowing, nutrition and crop protection.

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Managing wheat growth

Crop managers need to respond to unexpected weather or growth throughout the season.

The steps in any management cycle are to:

1. set targets

2. assess progress

3. adjust inputs

4. monitor success.

Measurement is vital for effective management at every stage of a crop's progress.

In addition to assessments on weeds, pests and diseases, managers must assess the crop itself. Crop assessments should be objective, targeted and, where possible, measured.

This guide presents measurements by which grain production targets can be set and progress monitored. It also explains how measurements interrelate.

Wheat growth stages

The Decimal Code system for measuring wheat growth used throughout this guide is based on work published in Tottman, DR & Broad, H (1987) *The decimal code for the growth stages of cereals, with illustrations*. Annals of Applied Biology **110**, 441-454.

Benchmarks for grain production

The sign identifies a benchmark*, defined for this document as a quantitative reference point against which a crop's performance can be compared. While benchmarks are compatible with good yields, they should not necessarily be regarded as management targets.

Page 4 gives the important growth stages and page 5 the benchmark values for key processes. All benchmarks are then explained in subsequent sections.

Each benchmark is based on observations of a high-yielding feed wheat with a slow rate of development at UK sites through several seasons. Unless otherwise stated crops were sown in early October at 375 seeds/m^2, and grown with ample nutrition, complete crop protection and without lodging.

Note that some graphs used to illustrate growth processes are based on example crops and so may give data that differ from benchmarks. Some benchmark data for modern varieties can be found within the HGCA Recommended List datasets (www.hgca.com/varieties).

By assessing crops against benchmark values, growers can determine how best to manipulate husbandry. Some targets and husbandry responses are suggested, but this is not an agronomy manual. More detail to support individual management decisions can be found in 'Further information' (page 30).

* *Benchmark* and other words in italics are defined in the 'Glossary' (page 29).

Wheat growth stages

Growth Stage	Description of stage
	Seedling growth
GS10	First leaf through *coleoptile*
GS11	First leaf unfolded (*ligule* visible)
GS13	3 leaves unfolded
GS15	5 leaves unfolded
GS19	9 or more leaves unfolded
	Tillering
GS20	Main shoot only
GS21	Main shoot and 1 tiller
GS23	Main shoot and 3 tillers
GS25	Main shoot and 5 tillers
GS29	Main shoot and 9 or more tillers

Growth Stage	Description of stage
	Stem elongation
GS30	Ear at 1cm (pseudostem erect)
GS31	First node detectable
GS32	Second node detectable
GS33	Third node detectable
GS37	Flag leaf just visible
GS39	Flag leaf blade all visible
	Booting
GS41	Flag leaf sheath extending
GS43	Flag leaf sheath just visibly swollen
GS45	Flag leaf sheath swollen
GS47	Flag leaf sheath opening

Growth Stage	Description of stage
	Ear emergence
GS51	First spikelet of ear just visible above flag leaf ligule
GS55	Half of ear emerged above flag leaf ligule
GS59	Ear completely emerged above flag leaf ligule
	Flowering
GS61	Start of flowering
GS65	Flowering half-way
GS69	Flowering complete
	Milk development
GS71	Grain watery ripe
GS73	Early milk
GS75	Medium milk
GS77	Late milk

Growth Stage	Description of stage
	Dough development
GS83	Early dough
GS85	Soft dough
GS87	Hard dough (thumbnail impression held)
	Ripening
GS91	Grain hard (difficult to divide)
GS92	Grain hard (not dented by thumbnail)
GS93	Grain loosening in daytime

Benchmarks for wheat growth

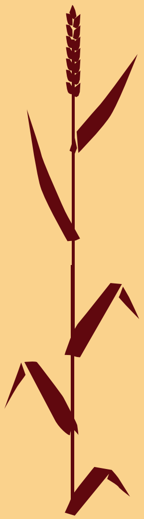
Benchmarks are reference values, compatible with high yields, but they are not management targets.

GS30	31 March	Ear at 1cm
Plants	260/m²	70% of seeds sown.
Shoots	941/m²	Tillering ceases when GAI>1.
Roots	0.4t/ha; 12km/m²	Little of the soil is yet fully rooted.
GAI	1.6	Only enough to intercept 45% of light.

GS31	10 April	First node detectable
Shoots	902/m²	Shoot numbers usually start to decrease from GS31.
Three leaves yet to emerge	28 April 9 May 19 May	One leaf emerges every 122 *day degrees*.
Roots	0.5t/ha; 15km/m²	Roots now reach to about 1m depth.
N uptake	81kg/ha	About 30% of final uptake.
GAI	2.0	Only enough to intercept half the light.
Total dry weight	1.9t/ha	Only 10% of final dry weight.
Growth rate	0.16 t/ha/day	During the Construction Phase (GS31-61).
Height to top ligule	9cm	Stem extension just starting.

GS39	19 May	Flag leaf blade all visible
Fertile shoots	655/m²	Some young shoots are still dying.
Total leaf number on main shoot	14	No further leaves emerge.
N uptake	189kg/ha	Increasing by 2.5kg/ha/day.
GAI	6.2	Enough to intercept 95% of light
Total dry weight	6.9t/ha	About 40% of maximum growth.
Height to top ligule	34cm	Late PGR reduces subsequent extension.

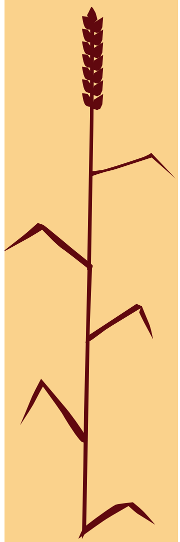
GS59	6 June	Ear completely emerged
Fertile shoots	495/m²	Little further shoot death occurs.
N uptake	233kg/ha	36kg N/ha green area.
GAI	6.3	GAI reaches its maximum about now.
Total dry weight	11.4t/ha	Growth may slow if flowering is delayed.
Height to collar	53cm	Five internodes extend.



GS61	11 June	Start of flowering
Fertile shoots	460/m²	150 additional infertile shoots/m² remain until harvest.
Roots	1.0t/ha; 31km/m²	Sufficient for full moisture capture to 70cm depth. Deepest roots reach to ~1.5m. Root growth now slows.
N uptake	248kg/ha	Only 30kg/ha further uptake occurs.
GAI	6.3	Canopy senescence is slow.
Total dry weight	12.1t/ha	About two-thirds of maximum dry weight.
Growth rate	0.18 t/ha/day	During the Production Phase (GS61-GS87).
Height to collar	69cm	Little further extension occurs. Ear length adds about 10cm.
Stem dry weight	7.1t/ha	33% is soluble, giving 2.3t/ha for redistribution.
Ears	1.9t/ha	Ears have 48 grain sites after flowering. Each ear weighs 420mg (dry) both now and as chaff at harvest.

GS71	20 June	Grain watery ripe
GAI	5.7	Rapid senescence now starts.
Stem dry weight	7.6t/ha	Now at its maximum. Rapid redistribution of soluble reserves begins at GS73.
Total dry weight	13.7t/ha	All further increase occurs in the grain.

GS87	29 July	Grain at 'hard dough'
GAI	1.3	All greenness will be lost in the next few days.
Total dry weight	19.6t/ha	About 0.8t/ha is subsequently lost, mainly from the straw.
Grain filling	Lasts 45 days	Grain filling stopped at about 45% moisture, about 3 days before GS87.



Harvest ripe	9 August	
Ears (fertile shoots)	460/m²	At least 400 shoots/m² required to avoid yield loss.
N uptake	282kg/ha	68% of final crop N is in grain, 32% in chaff, straw and stubble.
Total dry weight	18.4t/ha	51% grain, about 10% chaff, the rest as straw and stubble.
Straw dry weight	7.3t/ha	Includes stems and leaves; only 0.2t/ha soluble sugars remains.
Chaff dry weight	2.0t/ha	Chaff is 430mg/ear.
Grain weight	50mg at 15% moisture	Specific weight 78kg/hl.
Grain protein	11.5% (dry basis)	Calculated as 1.96%N x 5.7.
Grain yield	11.0t/ha at 15% moisture	Shedding losses are 0.03t/ha.

Crop life cycle

Throughout the growing season, the plant both changes in form (development) and accumulates dry matter (growth).

Key facts

- Development is governed by temperature and daylength.
- The rate at which wheat passes through its life cycle may only be managed through choice of sowing date and of variety.

The key phases

At successive growth stages crop processes 'switch' on or off. Key stages are crop emergence (GS10), the start of stem extension (GS31), *flowering* (GS61) and the end of grain filling (GS85). These key stages separate the important phases.

Crop development can be divided into three phases: Foundation, Construction and Production

Foundation Phase – six months

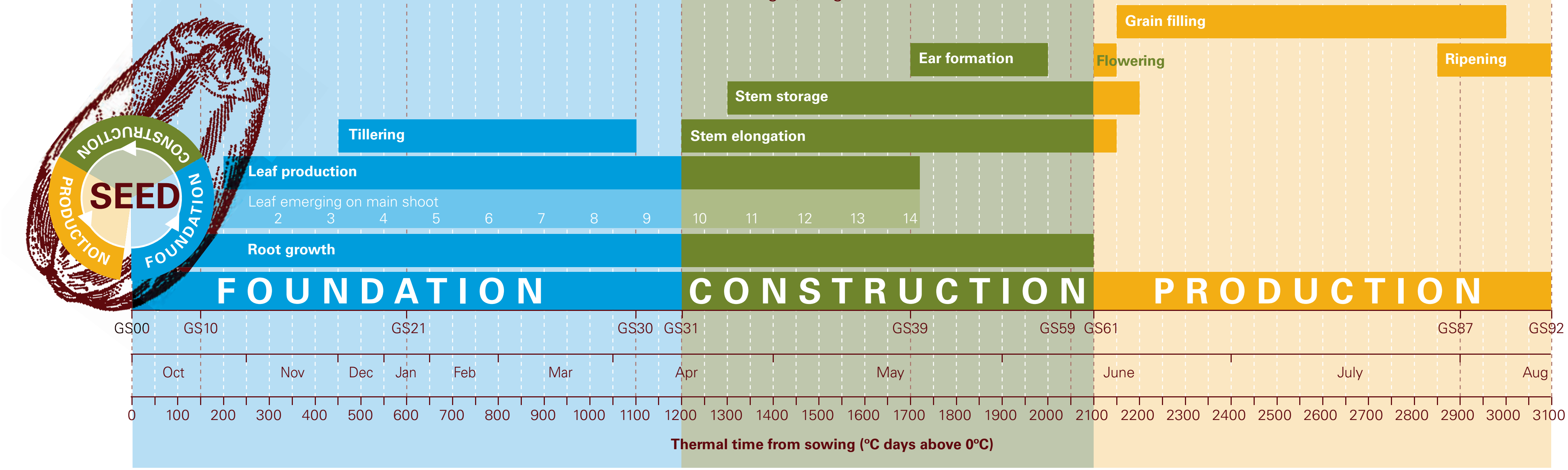
– **From sowing to the start of stem extension.** Yield-bearing shoots and primary roots form. The canopy is incomplete and light is dull, so growth is slow.

Construction Phase – two months

– **From first node to flowering.** Yield-forming leaves, fertile *florets*, stem reserves and deep roots form. Canopy is complete and light is bright, so growth is fast.

Production Phase – two months

– **Post-flowering – grains fill and ripen.** Light is bright but canopy survival and activity depend on good crop protection and ample uptake of nitrogen and water.



Development phases

The duration of each phase is governed by:

Vernalisation: a period of cool temperatures (0–12°C) advances floral development. *Vernalisation* reduces the duration of the Foundation Phase. Winter wheat varieties respond strongly to vernalisation; spring wheats may have a slight response.

Temperature: affects the duration of all crop development phases. Warmth shortens phase length. More growth occurs in any phase during cool, rather than warm, temperatures as phase duration is prolonged.

Daylength: long days advance floral development in most varieties. Daylength affects the duration of both Foundation and Construction Phases. Almost all commercial UK wheat varieties respond to daylength.

Varieties vary in their response to vernalisation and daylength. **HGCA Recommended List** tables give the relative speed of development of varieties to reach GS31 from early, medium and late sowings. They also provide conservative times for the latest safe sowing date for each variety to allow sufficient vernalisation to trigger flowering. The data are updated each year so always use the current version.

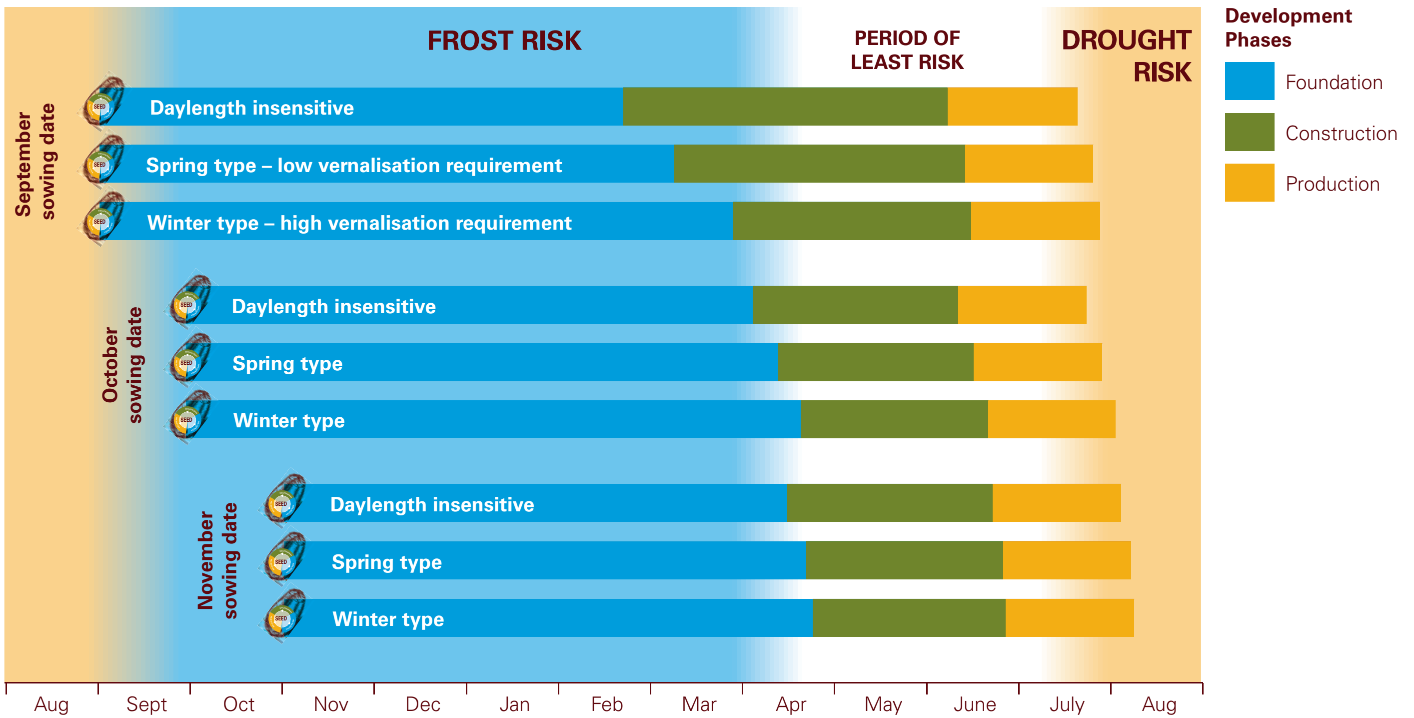
Stress-sensitive stages

The apex is frost tolerant until reproductive development starts.

Susceptibility to frost damage is highest when the ear is developing. Frost risk falls significantly from April. Overall risk of damage is lowest in late May and early June; from July onwards drought risk increases.

Radiation frosts can damage the ear, especially at flowering, which can significantly reduce yield; by comparison damage to leaves results in less yield loss.

Schematic diagram showing how frost and drought risks depend on variety type and sowing date



Crops are at least risk if Construction and Production Phases start when frost risk is over and end before drought risk starts.

This figure illustrates current theory. Further research will verify development of variety types.

What does it mean?

Development can only be managed by variety choice and sowing date.

Prolonging any development phase increases *dry matter* formation during that phase.

– *Prolong development by sowing slow developing varieties early.*

For a given variety and sowing date, management after sowing influences growth, not development.

– *For highest yields, feed and protect leaves that emerge during stem extension in preference to earlier ones.*

Establishment

Establishment includes germination, emergence and overwinter survival, expressed as percent of seeds sown.

Key facts

- Poor establishment or low plant population density does not reduce yield, unless:
  - significant areas of the field have very few or no plants
  - conditions are unsuitable for compensatory *tillering* and root growth.
- Establishment decreases from around 70% for sowings in September to less than 50% for sowings in November or later.
- Soil type and cultivations can have large effects on establishment: average establishment for sandy soils is 90%, compared with 65% for loams and clays.
- Plant density markedly affects crop structure but has little effect on grain yield, above a low threshold.
- High seed rates, coupled with good establishment, increase *lodging* risk.

Sowing to emergence

⊼ 150°C days

– 11 days in September

– 15 days in October

– 26 days in November

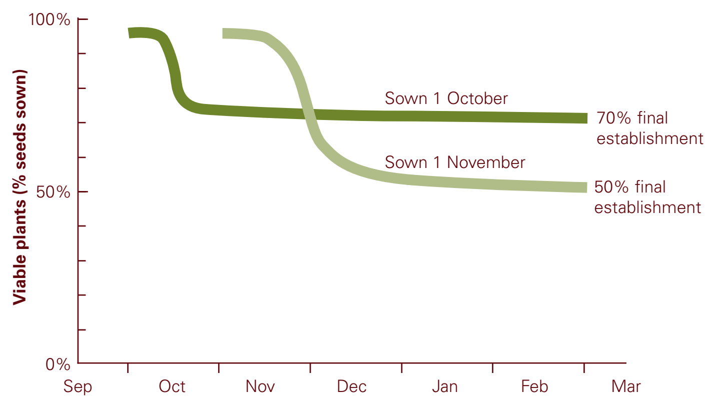
Germination and emergence require moisture and warmth. Initially seeds imbibe water; roots start to grow; coleoptiles emerge and extend to the soil surface. Then first leaves emerge and seedlings establish.

A proportion of viable seeds fail to emerge due to pests, diseases and soil conditions. Establishment declines if sowing is delayed after mid-October. Establishment will be around 50% of seeds sown in mid-November.

While sowing to emergence takes longer in cold than in warm weather, the *thermal time* in each case is very similar. Delayed drilling, deep drilling, cool and dry conditions extend the interval between sowing and emergence.

Sowing too deep or too shallow can delay or decrease establishment. Optimum sowing depth is about 4cm.

Establishment declines as sowing is delayed



Overwinter survival

⊼ 260 plants/m^2

⊼ 70% of seeds sown

By end-February, the benchmark for establishment is 70%. Plant damage, or loss overwinter, may occur due to:

- frost damage, especially after early drilling of fast developing varieties
- *frost heave*
- pest or disease damage
- poor, or impeded, drainage leading to poor rooting and *waterlogging*.

Tillering tends to compensate for uneven establishment. It may be possible to counteract poor establishment by using fertiliser N to encourage tillering and tiller survival.

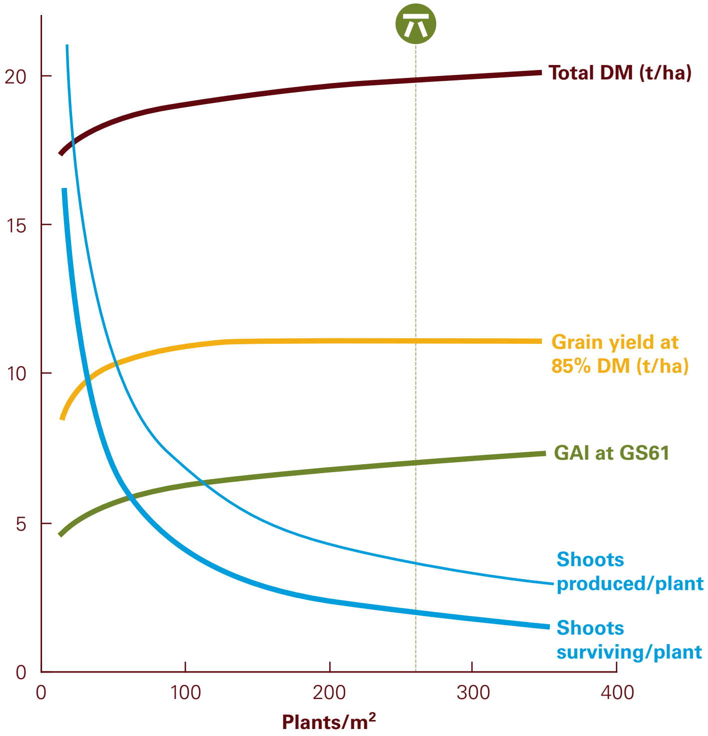
Very few plants die after winter.

Effects of plant population

Plant density depends on seeds sown and establishment. Eventual crop structure is markedly affected by surviving plants/m². Higher plant densities cause:

- fewer crown roots on each plant
- fewer tillers on each plant
- more fertile shoots survive, hence more ears/m²
- smaller culm leaves, but greater canopy size (*GAI*)
- fewer grains on each ear
- little change in grain yield, above a low 'threshold'.

Plant number affects many aspects of crop development and production



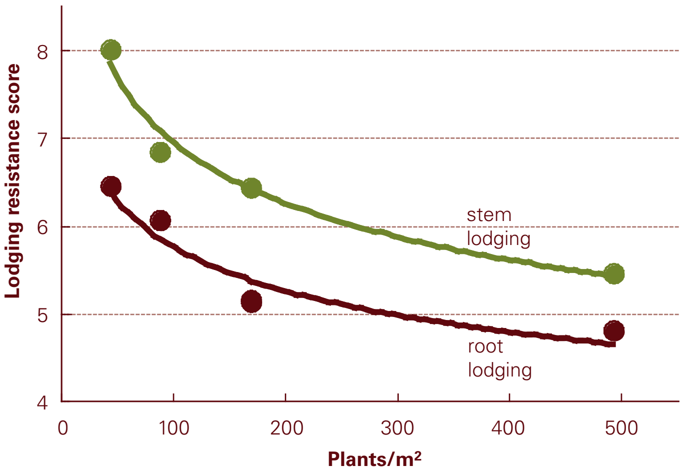
Lodging

High plant population density weakens plant anchorage. It also increases shoot height, and decreases stem diameter and stem wall width. This weakens stem base strength.

The benefit of low plant populations is greatest for varieties with poor lodging resistance.

Shallow drilling can increase lodging risk.

Lodging resistance decreases at higher crop densities



Source: HGCA-funded research

To achieve a target plant population in spring, seed rate should be set in seeds/m² and adjusted for expected establishment after overwinter losses.

Calculating a seed rate:

$$\text{Seed rate (kg/ha)} = \frac{\text{Target plant population (plants/m}^2\text{)} \times \text{Thousand grain weight (g)}}{\text{Expected establishment (\%)}}$$

What does it mean?

Soil type and cultivations affect establishment. For example, average establishment on sandy soils is 90%, compared with 65% on loams and clays.

Cultivations affect seedbed quality and establishment, depending on *soil stability* and type.

- *Consider deep cultivation on unstable silt soils.*
- *Consider reduced tillage on stable clayey soils.*

Other factors that may affect emergence and establishment are:

- *germination capacity (seed quality and vigour, which are affected by variety or seed crop ripening)*
- *some seed treatments may delay/reduce emergence, especially of deep-sown seeds*
- *high seed rates can lead to reductions in percentage establishment*
- *sowing too deep or too shallow*
- *disease or pest damage.*

Seed rate

Delayed sowing reduces the tillering period; for each month drilling is delayed, an extra 50 plants/m² are needed to compensate for reduced tillering.

- *Increase seed rates with later sowings.*

Leaf emergence, tillering and shoot survival

Leaf emergence indicates plant development and sets tillering potential.

Key facts

- **Rate of leaf emergence is controlled mainly by temperature.**
- **Each *main shoot* produces 9 to 14 leaves, of which 5 to 7 are on the extended stem.**
- **At least 400 fertile shoots/m^2 (400 ears/m^2) are required.**
- **All varieties can produce many tillers.**
- **Early sowing and fertile soils increase tillering.**
- **Tillering is prolonged at low plant populations.**
- **Many tillers die between GS31 and flowering.**
- **High N supplies encourage tiller survival.**

Leaf emergence

122°C days/leaf (14 main shoot leaves)

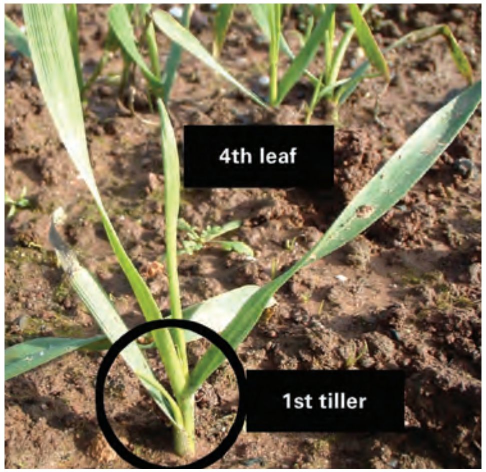
Leaf emergence slows or stops in winter and progressively speeds up as temperatures rise in spring.

Other environmental factors have little effect on leaf emergence.

The *phyllochron* is the time between emergence of two successive leaves, measured in thermal time.

The phyllochron varies with variety and sowing date. Late sowing decreases both phyllochron and total leaves emerged, eg early September drilling may give 15 leaves; November drilling may give 9 leaves.

T1 fungicides generally target the third from last leaf which normally coincides with GS32 depending on sowing date and variety.



The first tiller emerges in the junction of the first leaf (or coleoptile) as the second, third or fourth leaves emerge.

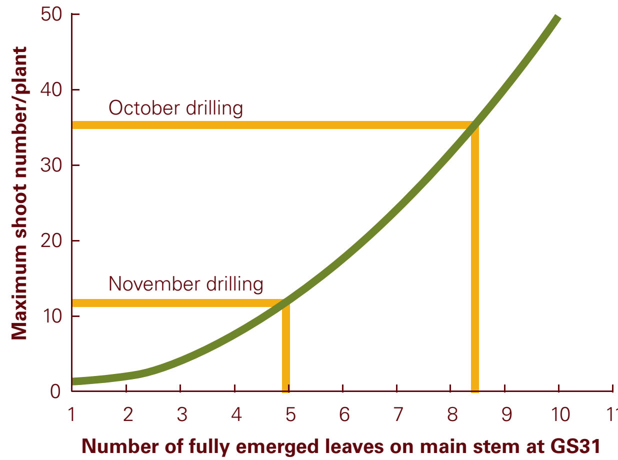
Potential tiller production

35/plant

Tillering is the emergence of side shoots at leaf-stem junctions. It can continue until after the start of stem extension.

The first tiller emerges in the junction of the first leaf (or coleoptile) as the second, third or fourth leaves emerge. The next tiller develops in the second leaf junction one phyllochron later, and so on. Secondary tillers develop in leaf junctions of primary tillers. Well-spaced plants can produce fertile tillers until stem extension starts; tillers produced later are rarely fertile.

Potential fertile tillers depend on leaves present at stem extension



The benchmark crop, sown in early October, produces 8-9 leaves by stem extension, so can produce a maximum of 35 shoots on each plant. November-sown crops may have only 5 leaves by stem extension with a potential for 11 or fewer shoots. This relationship is useful in assessing minimum plant numbers needed at establishment to give at least 400 ears/m^2.

Tillering patterns

1020 shoots/m² (8 April)

The timing of tillering depends on sowing date, plant numbers established and temperature.

Early sowing (early September) – most tillering occurs in autumn. If more than 250 plants/m² are established, then tillering usually ends before winter. If under 100/m² are established, tillering can continue into spring.

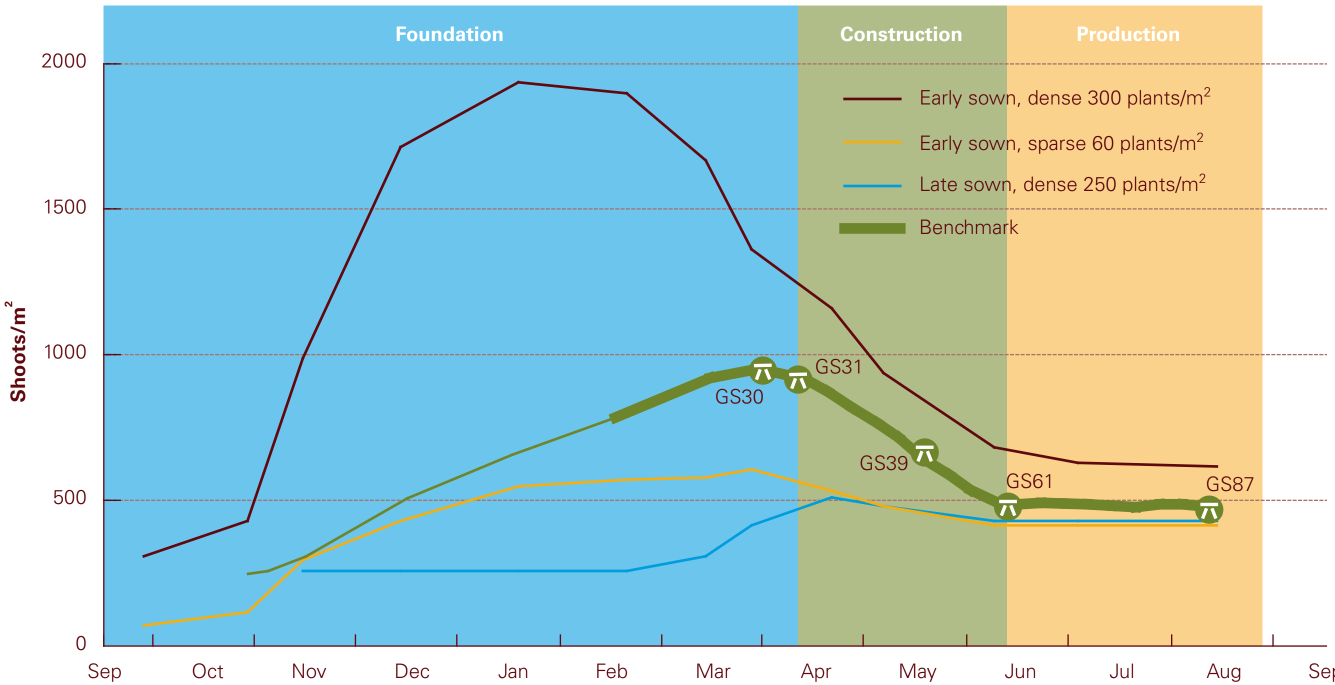
Late sowing (November) – tillering is usually delayed until spring unless unusually warm temperatures follow drilling.

Tillering normally ends when *Green Area Index* (GAI) reaches about 1. In dense crops, this usually occurs just before GS31.

Limited resources, especially N, may limit tiller production.

The benchmark maximum for a late September/early October-sown crop with 260 plants/m² is 1020 shoots/m². The benchmark date of maximum shoot number is in early April. Early-sown crops, or crops with many plants/m² tend to have greater maximum shoot numbers. Varieties with large leaves, or that reach stem extension early, tend to have lower maximum shoot numbers.

Tiller production and survival



Source: HGCA-funded research

Shoot survival

45% (460/m²)

Some tillers die between the start of stem extension and flowering, with the last formed dying first. Few die after flowering. Tiller losses are higher in crops with many shoots.

Shoot survival is as important as shoot production in determining final shoot number.

Shoot survival varies significantly between varieties – under 40% to over 70%. However, all varieties can produce sufficient tillers.

Increasing N reduces tiller loss.

Dry matter losses of up to 3t/ha can occur as shoots die.

What does it mean?

Leaf emergence, together with disease risk, determines spray timings.

– *Generally target T1 fungicides at the third from last leaf, normally GS32.*

Tillering is the most important process governing canopy formation. Some tillers die between stem extension and flowering. Those that survive until flowering result in extra ears.

– *Manage the crop to achieve at least 400 ears/m² for maximum potential yield.*

Root growth and distribution

Soil structure, management and drainage have major effects on root growth and distribution.

Key facts

- **A mature root system has 20+ main roots per plant, with many branches.**
- **Root growth is slow in the Foundation Phase, more rapid in the Construction Phase, then slow during the Production Phase when dry matter is redistributed and roots senesce.**
- **Good, especially deep, rooting, will enhance crop growth when water or nitrogen is short.**

Foundation Phase

15km roots/m² at GS31 (0.5t/ha)

Roots begin to grow at germination, with three to six seminal roots emerging before the second leaf appears. These can grow deep and persist throughout the crop's life.

The number of additional crown roots, which develop from the stem base, relates to leaf and tiller numbers. Once the main shoot has three to four leaves, crown roots appear with thickened upper regions to anchor the plant. The mature root system has 20 or more roots on each plant, plus numerous branches.

In well-drained and well-structured soil, the rate of root extension depends on temperature. In autumn, if soils are warm, seminal roots can grow quickly (12mm/day). Extension and branching slow during winter, then increase in spring. By GS31, maximum rooting depth can exceed 1m and root dry weight is about 27% of that of the shoot.

Construction Phase

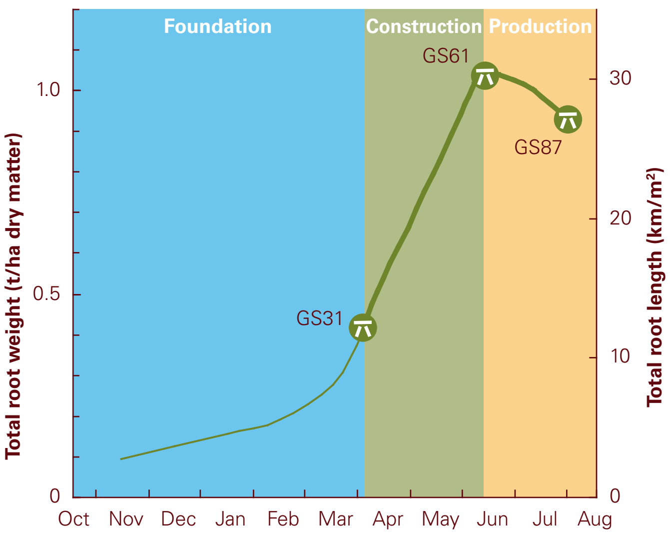
31km roots/m² at GS61 (1.05t/ha)

During stem extension roots grow rapidly. Root extension and branching increase as soil temperatures rise (main root extension of 18mm/day).

This is the main period of crown root production. However, dry matter may be lost as some roots die and as *assimilate* is exuded or respired. At GS61, root dry weight is 1.05t/ha (9% of the shoot) but twice as much assimilate may have been used in root growth.

With typical root distribution, total root length reaches 31km/m² by anthesis, and maximum rooting depth reaches 1.5–2.0m.

Root weight and length are proportional



Production Phase

27km roots/m² at GS87 (0.9t/ha)

After anthesis root growth slows, with only 10% of total assimilate produced during grain filling being used by the root system.

As roots in the topsoil begin to die, those in the subsoil may continue growing.

Protecting leaves with fungicides can prolong root growth and N uptake after GS61.

Sufficient roots are required for fully effective capture of water and nutrients at depth.

Root distribution: water and nutrient uptake

The relative distribution of roots down the soil profile changes little between GS31 and anthesis. Over 70% of root length is found in the top 30cm.

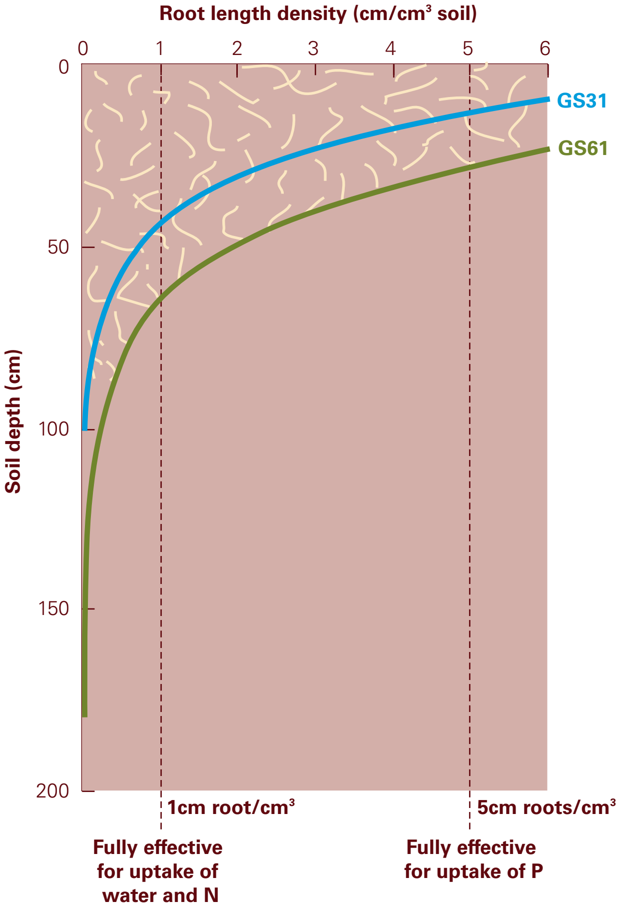
High rates of uptake of less mobile nutrients, eg P, only occur when root length densities exceed 5cm/cm^3 of soil. Lower root length densities are adequate for K, and about 1cm/cm^3 is needed for uptake of water and N.

Maximising root growth in the subsoil significantly improves soil water supply to the crop.

Typical main root extension rates in deep well-structured soil	
Autumn	12mm/day
Winter	6mm/day
Spring	18mm/day

Root distribution through the soil profile determines water and nutrient uptake.

Roots fully utilise water and nitrogen to about 40cm depth at GS31 and to 70cm depth by GS61



What does it mean?

Root systems can only be managed indirectly, through improved soil structure and drainage. Encouraging deep rooting will improve water or nitrogen supplies for crop growth. Varietal differences in crown root spread and low plant number can help to maximise root anchorage strength.

– *Sow early to increase overall root system size at flowering.*

Soil structure has a major impact on root growth and distribution. In some clay-rich soils, moisture extraction by roots promotes cracking, which improves soil structure and root access in following seasons. Hence, deep rooting can be self-sustaining, unless wheelings or cultivations destroy soil structure. With minimal tillage, enhanced earthworm activity creates long continuous pores in the subsoil to aid root penetration.

– *Consider field drainage and soil management to ensure adequate pore spaces for aeration and root penetration into the subsoil.*

Take-all reduces rooting at all depths.

– *Consider take-all control measures – seed treatment or foliar fungicide* – see **Take-all in winter wheat – management guidelines**, HGCA (2006).

Nitrogen uptake

Most N is taken up during the four to six week Construction Phase around May.

Key facts

- **N uptake can occur throughout the crop's life.**
- **Soils in arable rotations supply sufficient N for wheat to produce roughly half its potential yield.**
- **The other half of potential yield can be realised with applied N:**
  - **40% from the first half of N applied**
  - **just 10% from the second half of N applied.**
- **Fertiliser N controls canopy size, primarily through shoot number.**
- **N uptake is closely linked to canopy expansion.**
- **During grain filling a large proportion of N in leaves and stems is redistributed to grain.**

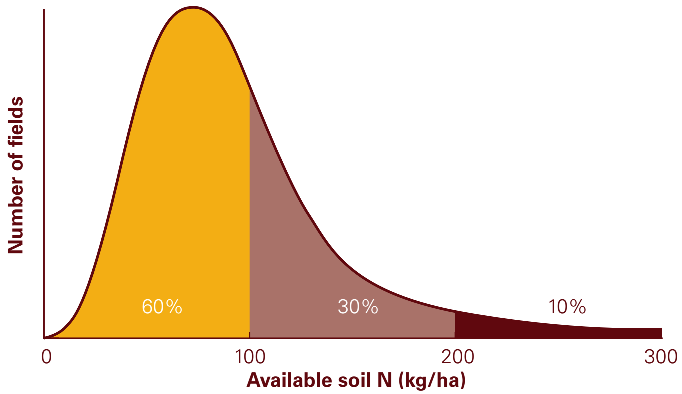
Sources of N

⊼ 75kg/ha available soil N

Soil N release and crop recovery are both very variable.

Seed contributes about 5kg N/ha while some 40kg/ha comes from the atmosphere, in rain and N-containing gases. However, most is acquired from soil. The benchmark is 75kg/ha available N (nitrate and ammonium) at SNS Index 1.

Variation in soil N in UK arable fields



Soil N availability is increased by unrecovered fertiliser from previous crops, vegetable waste or organic residues, eg legume roots or animal manures.

Soil N release is stimulated in warm moist soils, and after cultivations that thoroughly disturb the soil. Thus, much of the N from a previous crop is released in autumn, before sowing.

Crop residues with low N such as straw, can cause temporary unavailability through 'locking up' N.

Uptake of soil N continues throughout growth. Early sowing and unimpeded rooting improve soil N uptake.

Canopy nitrogen requirement

⊼ 36kg N/ha of green canopy

N uptake has a major influence on a crop's green canopy. The way that N controls canopy expansion depends upon the stage of crop development:

Stage of development	N uptake affects canopy size by promoting:
Before stem extension	Tillering
During stem extension	Shoot survival, with some increase in final leaf size
After stem extension	Prolonged survival of yield-forming leaves

Soil N is particularly prone to leaching when uptake is low due to slow canopy expansion over winter. As temperatures rise, canopy expansion accelerates and demand for N increases.

Throughout development the area of green tissues relates to the amount of N contained; there are about 36kg N/ha of green tissue. Thus, it is possible to control canopy size by controlling N availability.

Pattern of N uptake

81kg/ha from sowing to first node (GS31)

167kg/ha from first node to flowering

By harvest, a typical crop takes up 279kg/ha:

- 30% before first *node*
- 40% between first node and flag leaf (only 5 weeks); most is used to produce 'yield-forming leaves', ie the top four leaves within a crop's canopy
- 20% between flag leaf and flowering
- the remainder slowly after flowering.

N redistribution to grain

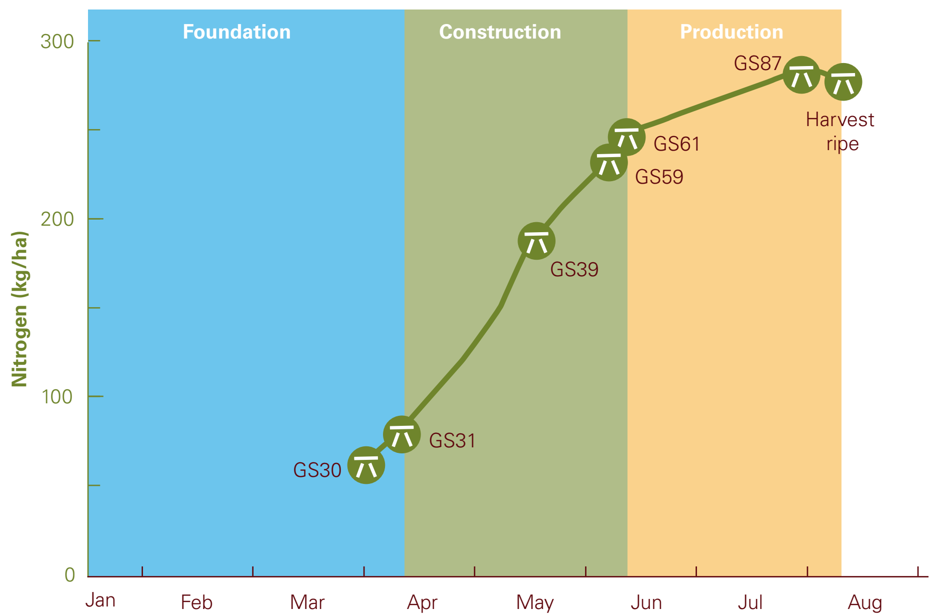
158kg/ha transferred to grain

90kg/ha left in chaff, straw and stubble

During grain filling there is a massive redistribution of N within the crop as proteins in the leaves are degraded and N is transferred to form grain protein. This, not root uptake, is the main source of grain N. At harvest, chaff, straw and stubble contain 90kg N/ha, 158kg/ha less than at flowering.

Occasionally crop N decreases slightly before harvest, probably due to loss of leaves.

Crop nitrogen uptake



This graph shows a pattern of N uptake compatible with other benchmarks. These values, and those for canopy N requirement and N redistribution, are greater than for most UK crops.

What does it mean?

Consider a 'canopy management' approach to N nutrition, using fertiliser N to achieve an optimum canopy size and adequate canopy survival through grain filling.

Soil mineral N analysis is a better predictor of available soil N than the SNS index, particularly where soil N residues may be large. It should include an estimate of crop N content at the time of soil sampling.

- *Obtain a good estimate of eventual soil N supply from soil analysis.*

Autumn N may occasionally be justified where soil N uptake over winter may be limiting.

- *Consider autumn N only where N availability may be inadequate over winter, eg on light soils with large amounts of surface straw, and after minimal cultivation.*

Early spring N is important for some crops.

- *Apply early N to encourage tillering after poor establishment, or to overcome root restrictions where there is soil compaction or a risk of take-all.*

Late spring N, after tillering is needed by most crops. It encourages rapid canopy expansion mainly through better tiller survival.

- *Use late spring N before the canopy turns pale, unless canopy size is excessive.*

Early summer N helps optimise canopy expansion and survival during grain filling.

- *Use early summer N, particularly for crops with pale, small canopies or with high yield potential.*

Late summer N ensures canopy survival through grain filling as well as adequate grain protein concentration for breadmaking.

- *Consider late summer N, particularly for crops intended for breadmaking, where yield potential is high and where field history indicates a need.*

Canopy expansion and death

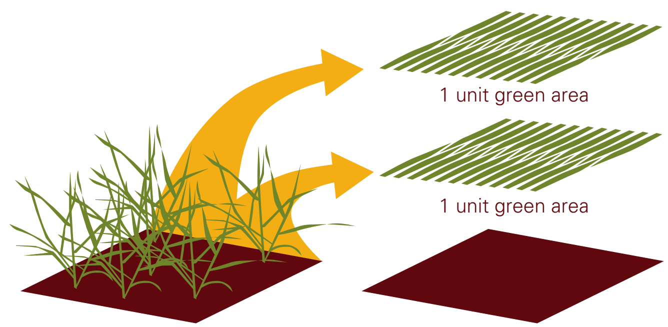
Managing canopy expansion and senescence is key to optimising crop output.

Key facts

- **Canopies go through three distinct phases:**
  - **slow expansion**
  - **rapid expansion**
  - ***senescence* and death.**
- **Canopy size determines the proportion of sunlight intercepted, and so dry matter increase.**

Canopy expansion starts at crop emergence and stops shortly after ear emergence. The canopy dies before harvest. Canopy size can be expressed as Green Area Index – the ratio of total green area (one side only) to the ground area occupied.

Illustration of GAI = 2 (two areas of green leaf and stem to one area of ground)



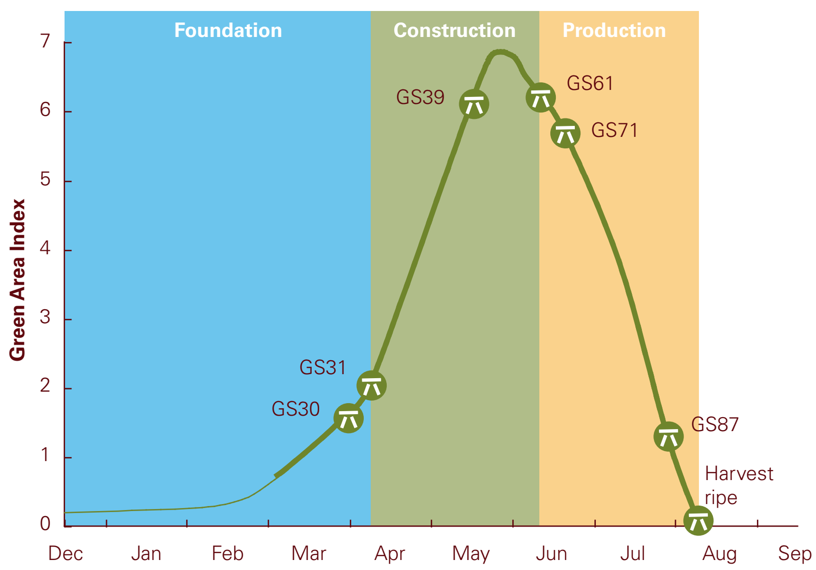
Foundation Phase – slow canopy expansion

GAI = 2.0 by GS31

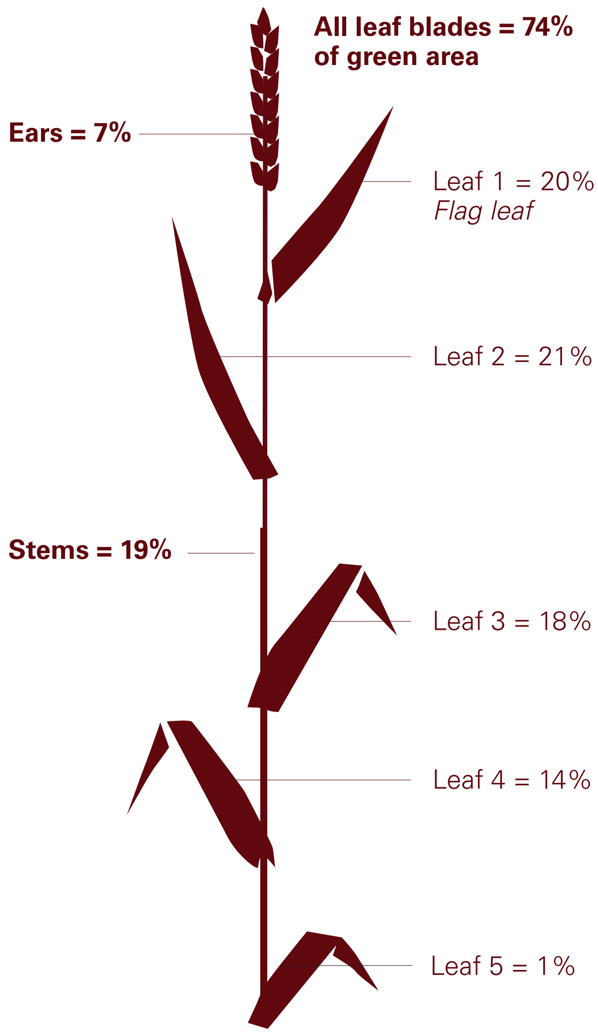
From emergence to early April ground cover increases. Cover increases as leaves and tillers emerge during early autumn and winter, but GAI rarely exceeds 1 before March.

During this phase *photosynthesis* and growth are slow because ground cover is incomplete; both light levels and temperatures are low.

Change in GAI over the growing season



Distribution of green area at flowering



Construction Phase – rapid canopy expansion

⩪ 1 GAI unit every 9 days

Ground cover is sufficient for rapid growth when GAI = 3.

Canopy expansion accelerates in late April as temperatures rise and the largest leaves emerge. As stems and *leaf sheaths* extend, they contribute to GAI. The benchmark rate of canopy expansion is 0.1 GAI/day. At this rate, crops expand by 3 GAI units during May.

Nitrogen availability controls canopy expansion quite closely because crop nitrogen for each unit of green area remains constant at 36kg/ha – the Canopy N Requirement (CNR). Nitrogen shortage curtails rapid canopy expansion or advances senescence.

At flag leaf emergence, *leaf blades* comprise about 85% of total GAI. The benchmark date for maximum canopy size, which occurs between flag leaf emergence and ear emergence, is 26 May. The benchmark maximum GAI is 6.9. Maximum canopy size occurs earlier in N-starved crops, as lower leaves begin to die.

Third and fourth leaves from the ear significantly increase GAI, but contribute little to grain filling.

Production Phase – canopy senescence and death

⩪ GAI falls to under 2 by GS87

The canopy senesces from June onwards. Lowest leaves die first, unless disease intervenes. Leaf sheaths usually die last. GAI drops below 2 on 27 July, coinciding with the end of rapid crop and grain growth. The canopy continues to respire, losing greenness and weight.

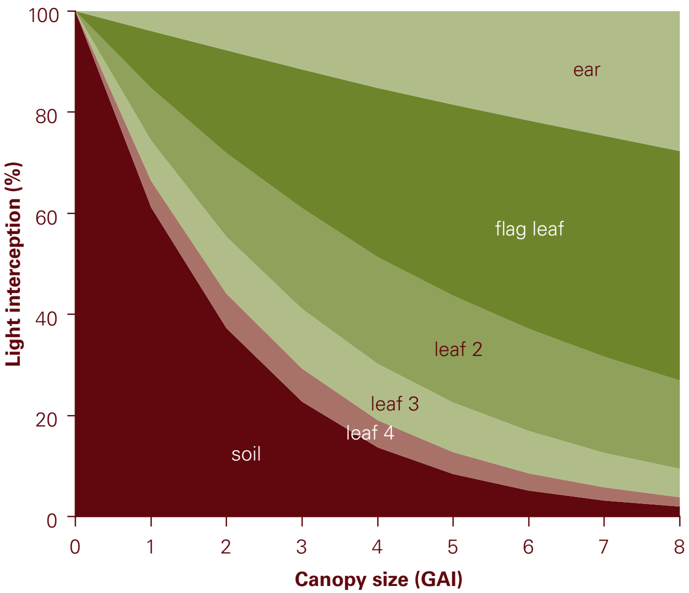
Canopy size and light interception

⩪ GAI at GS61 = 6.3

The crop canopy comprises all green surfaces – mainly leaf blades. At flowering, fertile shoots have a GAI of 6.0 and infertile shoots 0.3. The benchmark maximum green area for each fertile shoot is 130cm^2.

Husbandry has little effect on leaf number or size, so canopy management focuses on shoot number. As shoot number and GAI increase, the extra light intercepted decreases, eg an increase from GAI = 2 to 3 captures 15% more light, whereas only 2% extra is captured as GAI rises from 6 to 7. Upper leaves become more important for light interception as GAI increases (see below).

Light interception by crop increases with canopy size



There is an optimum canopy size at flowering for grain production of about 6.

- **Small canopies** (under 4), which waste sunlight, can result from inadequate plant or shoot survival, as well as N deficiency.
- **Large canopies** (over 7), which can result from high seed rates and high N supplies, cost more than is necessary to intercept all available sunlight. They are at high risk from foliar disease and lodging.

Optimum canopy size for varieties with erect leaves or low CNR only differ slightly from varieties with lax leaves. Differences in leaf greenness have little effect on photosynthesis.

Full light capture is hastened by early sowing, warm winters and springs, and adequate moisture and N.

What does it mean?

Achieving optimum canopy size is important for good yields.

Eventual canopy size tends to be increased by pre-sowing management:

- *early sowing*
- *high seed rate*
- *plentiful soil N*
- *adequate P and K, and correct pH.*

During the growing season canopy can be managed by:

- *amount and timing of fertiliser N applied*
- *disease control measures.*

Often canopy growth needs to be kept in check to avoid exceeding target GAI.

Dry matter growth

Dry matter growth represents the net effect of photosynthesis after losses from respiration and shedding.

Key facts

- **90% final crop dry matter is formed after GS31.**
- **No grain dry matter comes from the Foundation Phase; the Construction Phase contributes 20–50% with 50–80% from the Production Phase.**
- **The crop grows by 0.18t/ha/day, or 1.3t/ha/week from May to July.**
- **Crop growth on dull days is less than half that on bright days.**

Foundation Phase

⩪ 1.9t/ha growth by GS31 (9 April)

Over winter, growth is slow as canopy cover is incomplete and sunlight limited. Just 10% of total growth occurs by GS31 (6 months after sowing). Dry matter formed in this period produces leaves which are all lost before flowering with only their nitrogen being redistributed in the plant.

Root growth of about 0.5t/ha is additional to growth above ground during the Foundation Phase.

Construction Phase

⩪ plus 10.2t/ha growth by GS61 (11 June)

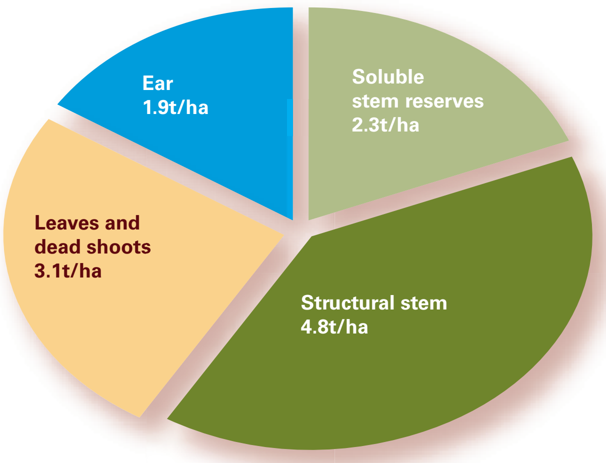
Rapid growth starts in late April as *internodes* start to extend, light interception approaches completeness and sunlight intensity increases. Over half of total growth occurs in this phase. Dry matter produced in this period supports at least 0.6t/ha extra root growth and the formation of all the organs vital to grain production.

Stem reserves act as a buffer. Reserves accumulate when photosynthetic rate is more than adequate, and fall when photosynthesis is inadequate, as in dull light.

Each fertile stem has a finite storage capacity for grain dry matter, determined by fertile *floret* numbers. The amount stored depends on how much dry matter is partitioned to the ear during booting and ear emergence. *Partitioning* differs between varieties.

Growth may slow towards the end of crop construction if storage capacity is already full.

Dry matter distribution at flowering



Production Phase

⩪ Plus 7.5t/ha extra growth by GS87 – 29 July, then 0.8t/ha loss

Rapid growth continues, although it slows slightly as leaves age and larger organs respire more in warmer weather. Soil water may also become limiting.

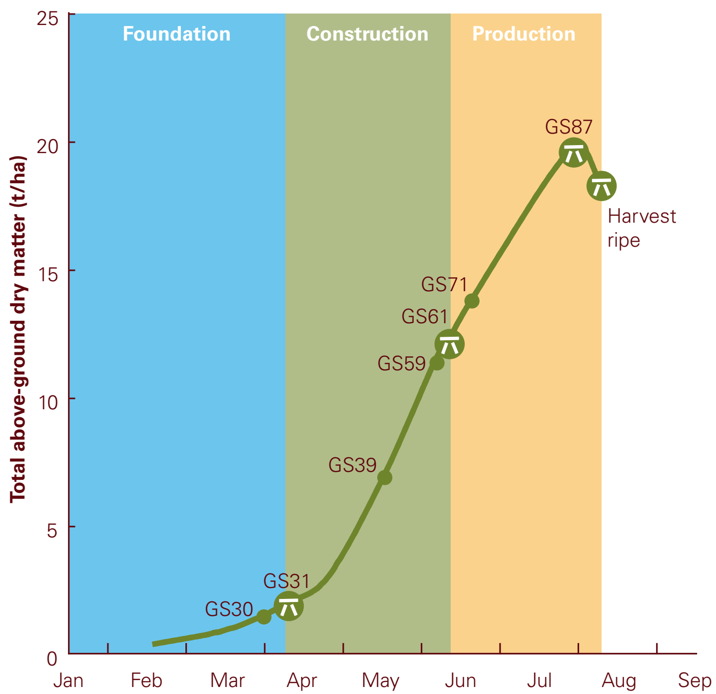
Only grains gain dry matter after flowering. Other plant parts (eg stems and leaves) lose weight, although chaff remains constant. As most soluble stem reserves produced pre-flowering are redistributed, grain growth always exceeds total crop growth during this phase.

Canopy senescence occurs as leaf and stem N moves to the grain. Thus, as grain proteins form, photosynthesis progressively slows. Senescence can be delayed if N and water uptake continue.

Rapid grain filling starts at GS71 and ends about GS87, even if green tissues remain. Early canopy senescence, often due to drought or disease, brings grain filling to a premature end.

Crop dry weight often decreases from its maximum, mainly due to ongoing *respiration*, but also through leaf loss. Dry matter is rarely lost from grain.

Change in crop dry weight over growing season



Growth

⩪ 0.18t/ha/day from May to July

Slow growth results from incomplete light interception or dull conditions. Rapid growth arises from complete interception of intense sunlight.

Respiration reduces dry matter, particularly when tissues are senescing.

Growth is driven by solar energy, as is water loss by *transpiration*, so photosynthetic rate is controlled by:

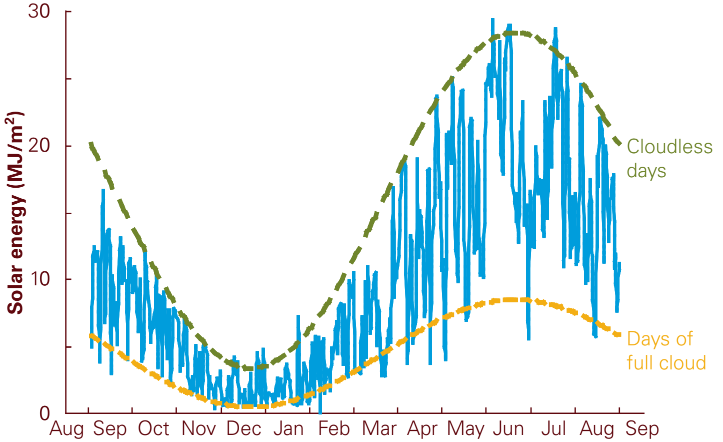
- light intensity
- green canopy size
- availability of water
- adequate storage for assimilates.

Resources for growth

Solar energy, carbon dioxide and water

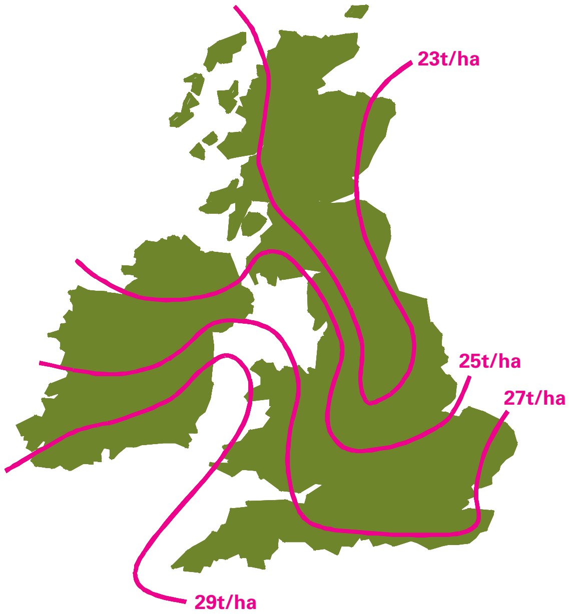
Assuming a full canopy, growth may be limited by the availability of solar energy, carbon dioxide or water. Low winter temperatures also occasionally limit growth.

Solar energy received by a crop is mainly governed by season and cloud cover



Solar energy: Dry matter growth in the UK usually relates directly to solar energy intercepted by the green canopy. About half of this radiation is photosynthetic.

Potential (light limited) growth – total dry matter*



**assumes interception of 60% average annual solar radiation*

Factors affecting interception of solar radiation are:

- region – southern regions have brighter sunlight. This is not fully counteracted by longer summer days in the north. Coastal areas have less cloud.
- canopy size,
- leaf posture, and
- foliar disease.

Light levels reach a maximum in May-July. On sunny summer days, growth can be 0.25t/ha. Clouds reduce light energy by about two thirds, so on dull days growth is just 0.1t/ha.

Theoretically, based on solar energy and rainfall, the south-west has the greatest potential for crop growth. However, cooler weather in the duller north prolongs wheat development and so increases grain yield.

Carbon dioxide: Atmospheric carbon dioxide is about 370 parts per million (ppm), and is increasing at about 25ppm a decade. In this range, crop growth relates almost directly to carbon dioxide concentration, so atmospheric change is increasing growth by about 5% a decade.

Variation in carbon dioxide concentrations is not significant on a regional or seasonal scale.

Water: To absorb carbon dioxide, leaves must lose water to the air in transpiration. On an average summer day transpiration uses about 3mm water. For each tonne of dry matter formed, the crop transpires about 20mm water. Drought restricts growth.

Factors affecting water availability for transpiration are:

- region – rainfall amounts and distribution
- soil type – moisture retention through summer, when transpiration generally exceeds rainfall
- soil depth and rooting
- take-all and other diseases – reducing root function.

What does it mean?

Growth can mainly be managed through the size of the crop's green canopy, taking light conditions and water availability into account.

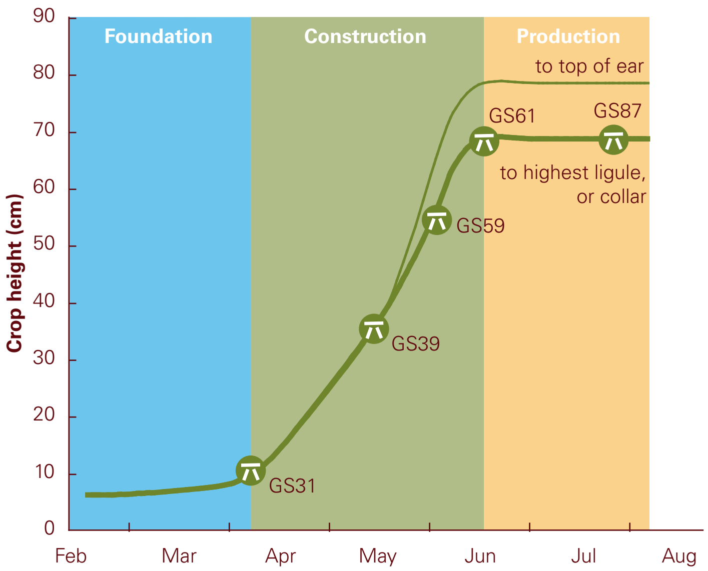
Stem extension

Crop height, determined by extension of the last five or six internodes, is a reflection of variety and growing conditions.

Key facts

- **Crop height is measured to the base of the last fully emerged leaf blade, or to the base of the ear. The ear adds a further 10cm.**
- **Crop height depends on extension of the five or six *internodes* forming the stem.**
- **Crop height is affected mainly by variety, sowing date and Plant Growth Regulator (PGR) use.**
- **Crop height is only one of several determinants of *lodging* risk in wheat.**

Increase in crop height



The extended stem

5 internodes measuring 69cm

Height before stem extension is related to leaf sheath length and reaches only 9cm by GS31. Final crop height results primarily from internode extension.

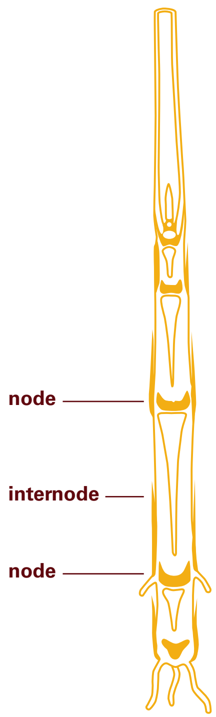
Each internode starts to extend when the previous one has reached half its final length. The benchmark number of nodes in a wheat stem is 4, giving 5 internodes. Crops sown earlier can have an extra internode and may be taller.

The benchmark final height is 69cm, with a full *PGR* programme.

Without PGR applications crops can be as much as 20cm taller.

By flag leaf emergence stem height is only 34cm (50% of final height). Stems extend to 53cm by full ear emergence (GS59) and reach their final height around the time of flowering (GS61).

Stem height does not reflect stem reserves or drought tolerance, as taller stems have a greater proportion of structural materials that cannot be remobilised.



Plant breeding and control of stem extension

Over recent decades plant breeders have introduced improved, shorter varieties containing reduced height ('Rht') and other dwarfing genes. Height varies by 16cm amongst contemporary varieties. In the HGCA Recommended List height is measured to top of the ear.

Agronomy and stem extension

The benchmark heights are for crops receiving applications of PGR during both early and late stem extension. Early sowing, high N residues, or lack of PGR contribute to tallness. The main effect of fertiliser N is to extend the penultimate internode and *peduncle*.

Height and lodging

In tall crops, the aerial parts of the plant impose a large force on the stem base and root system, but variation in crop height is only a minor contributor to lodging risk; other factors are weight distribution along the shoot, root anchorage and stem strength. All three components of lodging risk can be altered by choice of variety and husbandry – see **Avoiding lodging in winter wheat – practical guidelines**, HGCA (2005).

The earlier lodging occurs during grain filling, the greater the yield loss. Lodging can also adversely affect quality characteristics such as *Hagberg falling number* and *specific weight*.

Stem carbohydrate storage

Stem reserves contribute 20–50% of grain yield.

Key facts

- **Carbohydrate reserves are measured by weighing and analysing the sugar content of stems. They are the major part of the dry matter redistributed from stems and leaves during grain filling. Protein is also redistributed.**
- **Soluble carbohydrate stem reserves reach a maximum of 2.7t/ha between late booting and early grain filling.**
- **Varieties and growing conditions both influence stem reserves by up to 2t/ha.**
- **Grain filling normally depends on stem reserves and ongoing photosynthesis. By harvest, almost all stem reserves have been relocated to the grain or lost through respiration.**

Accumulation of stem reserves – GS31 until early grain filling

More assimilate is produced during the Construction Phase than is needed for structural tissues. The surplus is stored in stems as *fructan* sugar, mainly in the pith of upper internodes. About 25% is in the peduncle, 30% in the penultimate internode and 45% in lower internodes.

Stem storage capacity is set by stem number and structure. Maximum capacity can be reached by late booting (GS47). Reserves may be utilised during temporary shortages caused by factors such as dull weather before and after flowering. Reserves fluctuate with growing conditions from booting to early grain filling; they then decrease.

Maximum stem storage

⚖ 2.7t/ha soluble carbohydrate

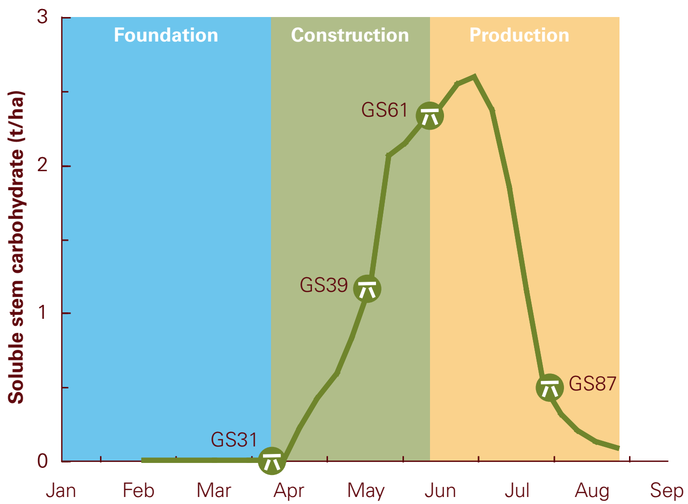
The benchmark amount of stem reserves at flowering is 2.3t/ha. An additional 0.4t/ha accumulates by early grain filling. Sometimes stem reserves reach their maximum before flowering.

Both variety and growing conditions can affect stem reserves by about 2t/ha. Some crops can store more than 4t/ha.

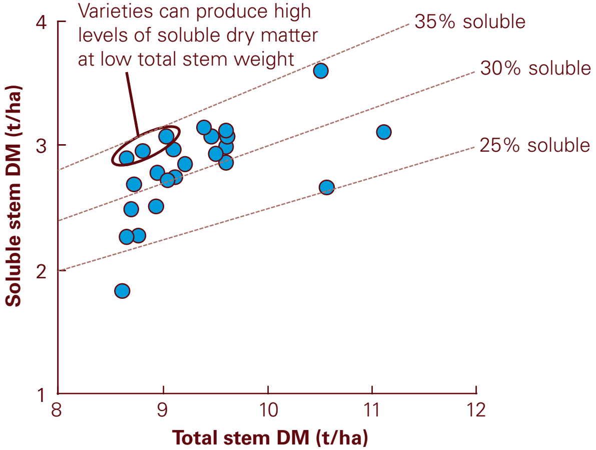
Varietal differences may be due to both total stem weight and percent soluble material. Recent UK varieties have 25-35% of stem biomass as soluble reserves. Stem height does not necessarily indicate larger stem reserves.

Environmental differences in stem reserves commonly relate to differences in stem number. Soluble stem *carbohydrate* is not affected by PGR applications.

Accumulation of stem reserves from GS31 to early grain filling



Soluble stem dry matter data for a range of varieties



Source: NIAB, 1996-2002

Dry matter redistribution during grain filling

⚖ 3.1t/ha soluble carbohydrate

Redistribution of soluble reserves lasts from 26 days after flowering to the end of grain filling. The loss in straw dry matter between flowering and harvest is 3.1t/ha comprising 1.9t/ha soluble stem reserves, as well as protein from leaves and stems.

Reserves contribute significantly to yield under all post-flowering conditions.

Varieties with highest yield potential tend to be those that accumulate greatest amounts of stem soluble carbohydrate. Stem reserves contribute similar amounts of assimilate in stressed or unstressed crops. However, because yields are less in stressed crops, reserves contribute a higher proportion.

Ear formation

Capacity for grain filling is set by grain number per unit area and the storage capacity of each grain.

Key facts

- **Ear weight increases rapidly during booting. Ear weight at flowering is the same as the weight of chaff at harvest, and relates closely to final grain number.**
- **Grain number per ear is largely controlled by survival of flower initials (florets) whilst the last leaves and ear are emerging.**
- **Grain number per ear is an important yield component.**
- **Ear weight at flowering can indicate grain numbers and hence storage capacity of the ear.**

Ear development

20 days from flag leaf to ear emergence

Ears are initiated during the Foundation Phase and *spikelet* initiation is completed as stem extension starts (GS31). Floret initiation and development then proceed until flowering. The number of potentially fertile florets depends on assimilate supplies to the ear, particularly during booting and is affected by shoot numbers. At shoot numbers of over 400/m², mutual shading results in fewer grains in each ear.

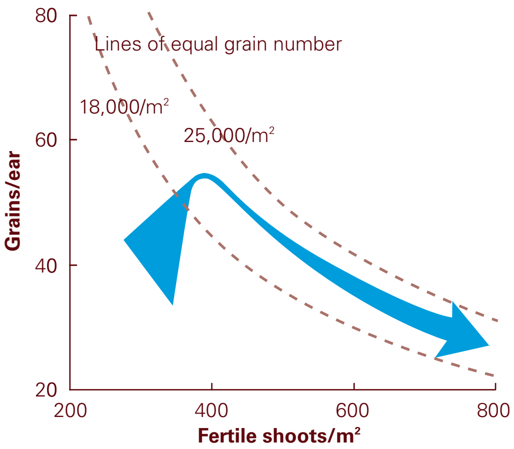
Weather conditions affect ear development, especially during booting and ear emergence. Cooler bright conditions in the one or two weeks before flowering can prolong or enhance the ear-formation period and increase grain number per ear. However, inclement weather at flowering, such as heavy rain, heat or drought, occasionally impairs pollination and reduces the number of fertilised florets.

Grain number

48 grains/ear – 22,000 grains/m²

The benchmark for grain number per ear is 48. With 460 surviving fertile shoots/m², this gives 22,000 grains/m².

Grain numbers compensate above 400 shoots/m²



Source: HGCA seed rate trials

Varieties with smaller culm leaves tend to have more shoots/m² and fewer grains per ear. Modern breadmaking varieties tend to have fewer grains/ear than other varieties.

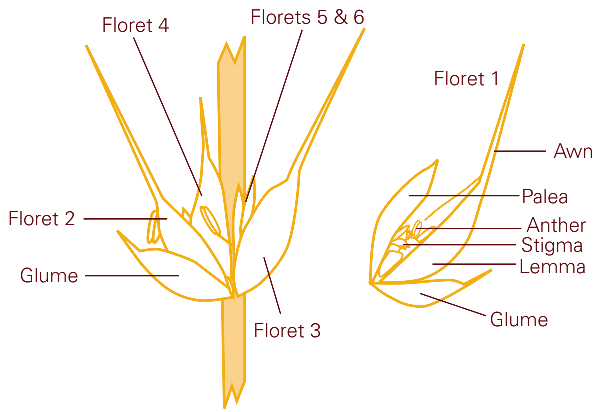
Insects, eg orange blossom midge, reduce grain numbers and feed on developing grains.

Ear weight at flowering

420mg/ear

By flowering the benchmark ear weight is 0.42g/ear, comprising glumes, florets and *rachis*. These components remain of similar weight through grain filling and become the chaff at harvest, so ear weight at flowering multiplied by fertile ear number per unit area can indicate yield potential.

Structure of a spikelet



Photosynthesis in the ear contributes significantly to grain growth. The benchmark final ear weight at harvest is 2.6g, of which 17% is chaff.

What does it mean?

In wheat, yield variation due to region, soil type and early crop management is strongly related to grain number, rather than weight of each grain. Severe disease or drought can significantly reduce grain size.

Grain filling and ripening

Grain filling depends on ear and leaf photosynthesis, as well as redistribution of stem reserves.

Key facts

- **Grain filling starts when flowering is complete and continues until grain reaches about 45% moisture.**
- **After flowering, grains swell – largely by water uptake. Rapid dry weight growth continues with starch and protein deposition in expanded grain cells. These are supplied by both current photosynthesis and redistribution of reserves.**
- **Where green canopy persists to the end of grain growth, stem reserves are less important.**
- **Ripening and moisture loss continue after grain filling until grain is dry enough to harvest.**

Grain filling

43mg dry matter per grain in 45 days until 26 July

Grain filling determines final dry grain weight. This final stage in yield formation influences grain appearance and specific weight.

Grains accumulate more water than dry matter for about four weeks after flowering, when water content is at its maximum. Water enables cells first to divide, then expand. Dry matter accumulation accelerates as water uptake stops.

Sub-optimal photosynthesis during the first two or three weeks of grain growth will reduce cell number and potential weight of each grain.

Grain filling depends on the capacity of both 'sink' (ie all grains in ear) and the 'source' (ie materials from photosynthesis and reserves).

- Where 'source' does not satisfy 'sink', eg due to late drought or disease, grains will be inadequately filled and, after *ripening*, may appear shrivelled.
- Where 'sink' is too small to store all of the assimilate from the 'source', grains will be plump, and the adverse effects of drought or disease on yield are reduced.

The benchmark period from flowering until maximum dry weight (the grain filling period) is 45 days, but it varies considerably; it can be just 28 days in severe drought conditions. The benchmark weight per grain is 43mg dry matter, which equates to a 'thousand grain weight' of 50g at 15% moisture.

Varietal differences in average grain weight are shown in the HGCA Recommended List.

Canopy survival during grain filling

GAI <2, a day after maximum grain weight

Benchmark canopies lose most greenness just after grain weight reaches its maximum. Excessive N, fungicide usage or cool moist weather tend to delay senescence. Crops at northerly latitudes generally have high grain weight because cool temperatures prolong grain filling.

Hot weather reduces grain weight by shortening the period of grain growth, even in bright and moist conditions. Grain weight is also reduced by leaf or root disease, aphid infestation or early lodging.

Grains stop growing when their moisture content falls below 45%, when estimate of final grain yield can be made.

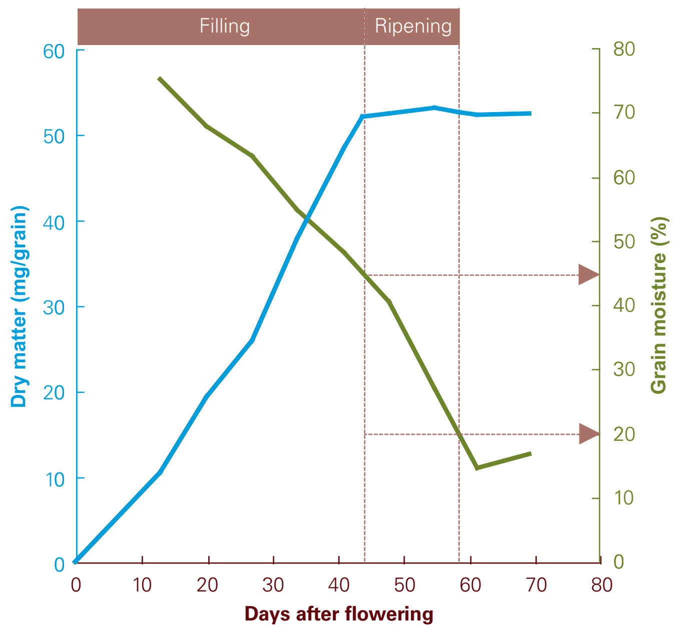
Ripening

Two weeks from 45% to 20% moisture

After filling, moisture content provides the best indication of ripening until grains are dry enough to harvest. Decreases in percentage moisture arise first through filling with dry matter (70%-45% moisture content) and then through water loss (45%-20% moisture content).

On average grain takes about two weeks to dry from 45% to 20% moisture. Frequent rain re-wets grain and slows moisture loss, especially at low moisture contents. Lodged crops dry slowly.

Grain filling continues until moisture content reaches 45%



What does it mean?

No further grain filling occurs once grain moisture is below 45%, so yield cannot be affected by any treatment applied at or after this stage.

- *Consider using a desiccant (approved for use at less than 30% moisture, GS91) if harvest timing is threatened by inclement weather.*

Grain yield and quality

Marketable yield depends on number of ears, grains in each ear and weight of each grain.

Key facts

- **Grain dry weight usually constitutes about half of final crop dry weight.**
- **Grain yield can be estimated by multiplying together ears/m², grains per ear and weight of each grain (derived from thousand grain weight) which are determined at successively later stages in the life cycle.**
- **Grain yield is measured as the weight of grain recovered from an area of crop, corrected to a moisture content of 15%.**
- **Specific weight partly depends upon grain size, also on grain density and grain packing characteristics.**
- **Hagberg falling number reflects the gelling properties of flour made from whole grain.**

Grain yield

11.0t/ha at 15% moisture

Grain is the principal product of crop growth, especially in June and July. Yields therefore depend on the state of the crop leading into this period and then on growing conditions during this period.

In experiments, yields may be determined by combine harvester or by hand-harvesting crop from a quadrat of specified land area. The benchmark crop yielded 11.0t/ha by both methods, when corrected to 15% moisture.

Yields vary with variety (see **HGCA Recommended List**) and growing conditions, as affected by soil, weather and husbandry.

Yield components

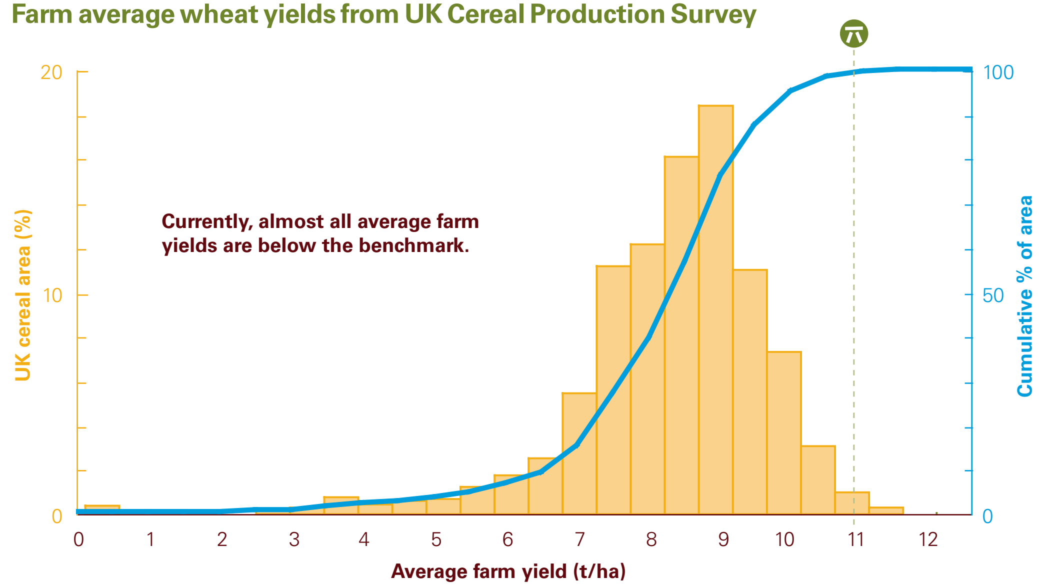
460 ears/m²
48 grains/ear
50mg/grain
at 15% moisture

Ear number/m², grains per ear, and grain weight are key yield-determining attributes at harvest. Their values are related to the success of different growth phases:

- ear number reflects growth from the start of tillering to flag leaf appearance (GS39)
- grain number per ear reflects growth from GS39 to flowering (GS61), and
- individual weight per grain reflects growth after flowering.

Each phase partially compensates for the outcome of earlier phases. A crop with a sparse shoot density tends to produce more grains per ear and heavier grains than a thick crop.

Farm average wheat yields from UK Cereal Production Survey



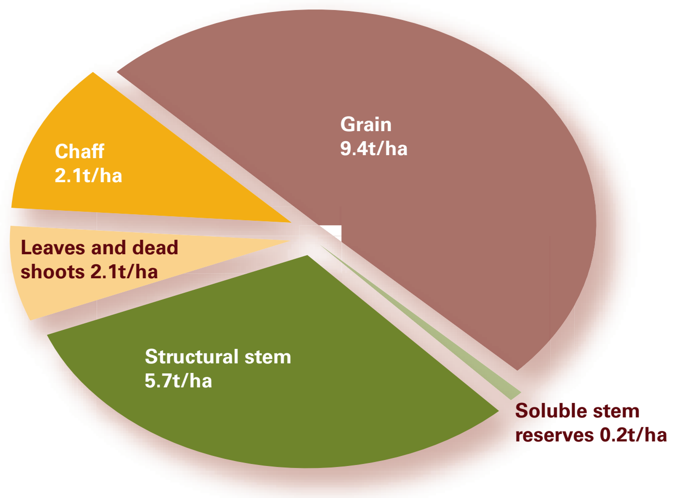
source: Defra

Final distribution of dry matter

⊼ 18.4t/ha dry matter with 51% Harvest Index

Harvest Index is the ratio between grain yield on a dry basis and the total crop dry weight at harvest. This ratio is variable.

Final dry matter distribution



The benchmark dry matter of the harvest-ripe crop is 18.4t/ha, of which 9.4t/ha is grain (equivalent to 11.0t/ha at 15% moisture).

The remaining 9.0t/ha of dry matter includes straw, chaff and stubble, but only about half of this can be baled as straw, even when the height of the combine cut is low.

Much variability in crop dry weight comes through variable production of non-harvestable material. Plant breeders have been most successful in increasing harvest index; growers have been most successful in increasing total crop dry matter.

Specific weight

⊼ 78kg/hl

Crops with a large grain weight tend to have high specific weight. This is also influenced by:

- the density of individual grains
- the range of grain sizes
- characteristics of grain surfaces that affect packing.

Specific weight indicates the weight of grain that can be loaded onto lorries or ships. A typical requirement for milling or export is 76kg/hl; samples below this standard are likely to incur price penalties or even exclusion from the intended market. Late harvesting can reduce specific weight through weathering.

Hagberg falling number

⊼ 270

Hagberg falling number is a measure of the hot paste viscosity of a wholemeal water suspension. The minimum value possible is 60.

Values required:

- above 250 for breadmaking
- above 225 for export.

Lower viscosity results from starch breakdown by the enzyme alpha-amylase. This may form during or after ripening.

Enzyme activity is mainly associated with initiation of germination, and hence with sprouting. Alpha-amylase may also form in cool, wet weather during ripening, even in the absence of visible sprouting. Green grains on late tillers, or grains damaged by orange blossom midge also have high alpha-amylase.

Effects of husbandry on Hagberg falling number tend to be small and inconsistent compared to the effects of variety and weather.

Varietal differences in specific weight, *dormancy* and Hagberg falling number are indicated in the HGCA Recommended List. Group 1 wheats generally are classed as ‘very high’.

What does it mean?

By GS91 management can only protect against losses of yield or quality. Depending on intended market and likely risks, consider:

- *combining as soon as the crop is ripe*
- *assessing Hagberg falling number pre-harvest on hand-threshed, air-dried grain*
- *harvesting at high moisture to optimise chances of high Hagbergs.*

Grain protein deposition

Protein percentage is increased by protein deposition and decreased by starch deposition in grain.

Key facts

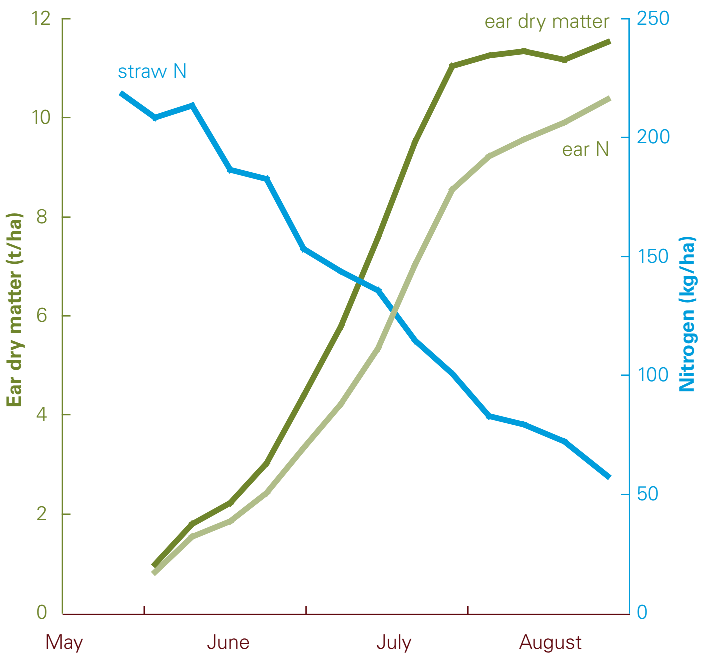
- **Grain protein is related directly to grain N. It is increased by protein deposition and diluted by other grain growth.**
- **N is redistributed from photosynthetic tissues during grain filling to form grain protein. N uptake post-flowering increases grain protein.**
- **Varietal differences in protein percentage are small relative to those associated with site, season and husbandry.**
- **Grain protein levels acceptable for breadmaking are more consistently achieved in second, than in first, wheat crops.**

Nitrogen redistribution
⊼ 158kg/ha N

Most grain protein is formed by redistributed nitrogen, 158kg/ha N coming mainly from stems, leaves and roots as they die. Only an additional 31kg/ha of grain N comes from uptake after flowering.

The straw and chaff contains 90kg/ha N at harvest – 32% of total crop N – making the N *harvest index* 68%.

N redistribution coincides with ear growth



Protein deposition
⊼ 189kg/ha N or 1.1t/ha protein

The weight of grain protein relates directly to the weight of N, with a ratio of 5.7 to 1. The benchmark amount of grain N is 189kg/ha, equating to about 1.1t/ha protein. Soil type, season and husbandry all influence grain protein deposition. Varietal differences in average grain protein are shown in the HGCA Recommended List.

Generally the later that N fertiliser is applied, the more grain N is increased. Applying urea as a spray when grain is milky ripe (GS75) has the largest effect on grain N, but normally has little effect on yield.

Grain protein concentration
⊼ 11.6% on a dry basis

High concentrations of grain protein can arise either from large N uptake or poor starch formation during grain filling. First wheats tend to have grain of low protein percentage, below that of second wheats, if both are fertilised optimally. Protein contents of first wheats are usually diluted by their greater yields.

Conversely, factors that reduce yield without affecting nitrogen transport to grain, for example, drought, early lodging or disease (eg take-all) may raise protein. Powdery mildew is an exception; it lowers protein percentage by interfering with nitrogen transport.

Measurements

To support husbandry decisions, comparisons with commercial crops must be made using careful in-field observations and measurements.

For quantitative assessments, at least four samples should be taken (one from each quarter of the field). In a variable crop more samples are required. Each sample point should be selected to represent the crop, but away from headlands, gateways and atypical patches.

Development or 'Growth Stages'

The decimal (or 'Zadoks') growth stage code should be used (see page 4). Assessments are restricted to main shoots until flag leaves emerge. To determine the growth stage of the crop as a whole, quote the middle (*median*) stage from an odd number of plants arranged in order.

For example:

If five plants were taken and their growth stages were:

33 37 **37** 39 39

then the crop would be considered to be at GS37.

Plant populations

Take at least four samples (more if variable) across the field. Either throw down a quadrat (a square frame) and count the number of plants inside it, or use a ruler. The number of plants growing along a measured row, divided by the row width and length, can be used to determine the number of plants per square metre, as follows:

$$\frac{\text{No. of plants counted in the row} \times 10{,}000}{\text{Row length (cm) x Row width (cm)}} = \text{Plants/m}^2$$

For example:

$$\frac{\text{15 plants counted in the row} \times 10{,}000}{\text{50 (cm) x 15 (cm)}} = \text{200 plants/m}^2$$

The same method can be used to work out shoot numbers/m^2, counting shoots instead of plants.

Crop canopy

Crop canopies are measured by their Green Area Index (GAI). This is the surface area of green material (one side only) divided by the area of ground it occupies. For example if, when all the green parts (leaves, shoots and ears) from 1m^2 of a field were separated and laid out adjacent and flat, they covered 2m^2, the crop would have a GAI of 2 (see page 16). If they covered 4m^2, the crop would have a GAI of 4, and so on.

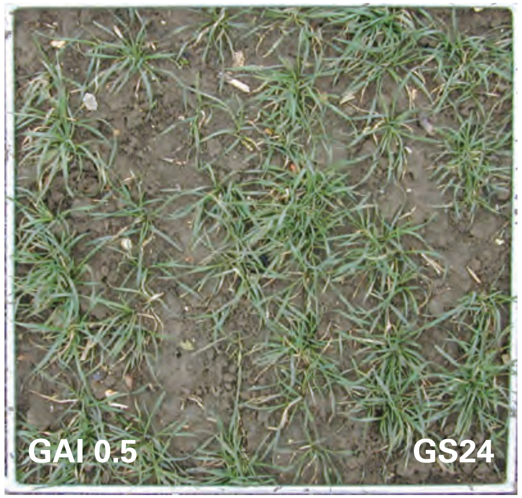
To avoid such a long and tedious process, it is better to 'get your eye in' and judge the GAI from the crop's appearance (see page 28).

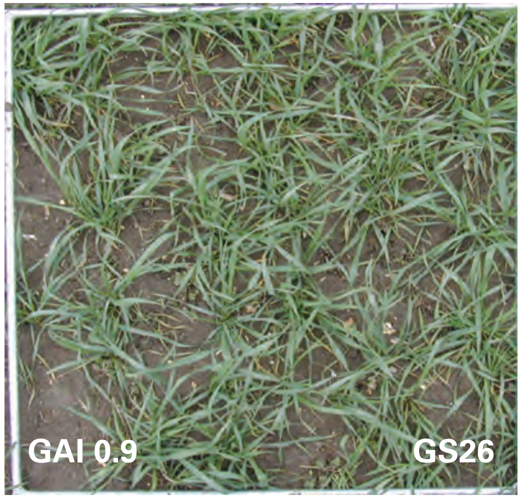
Instruments are available which can measure the reflectance or light intercepted by a crop and translate it into GAI. A combination of experience and calibration using such machines can give the assessor a sufficiently accurate picture of canopy size to support crop management decisions.

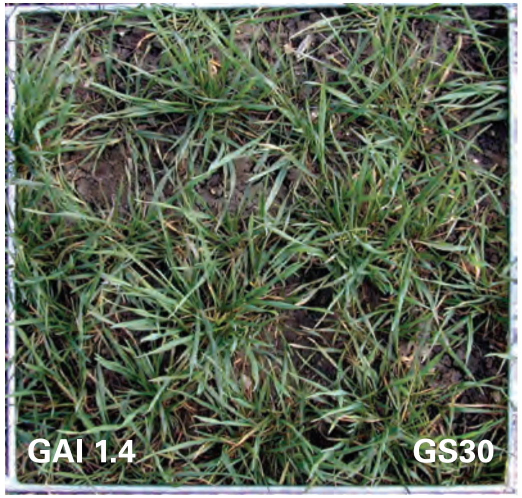
Dry weight

Dry weight is less easy to assess in the field than canopy size. However, measurements of ear dry weight can help in anticipating yield after the grain has reached 45% moisture. These can be made by placing a known number of ears in a domestic microwave at high power for 10–15 minutes, turning 2–3 times during drying. The resulting weight can be measured on a domestic digital balance in grammes, divided by the ear number, multiplied by 0.82 to correct for chaff, and multiplied by fertile shoot number per square metre to give the estimated grain yield (g/m^2) NB t/ha = g/m^2 ÷ 100.

Visual assessment of green area index (GAI)

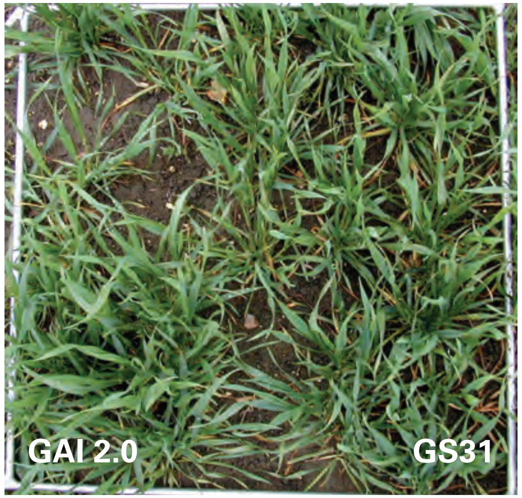


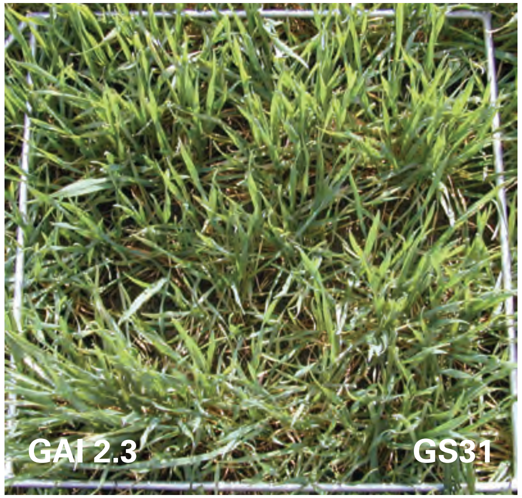




With practice it is possible to estimate a crop's green area index.

These photographs illustrate typical GAIs.





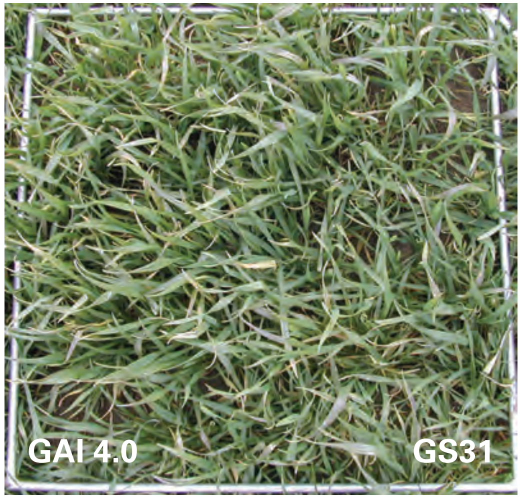
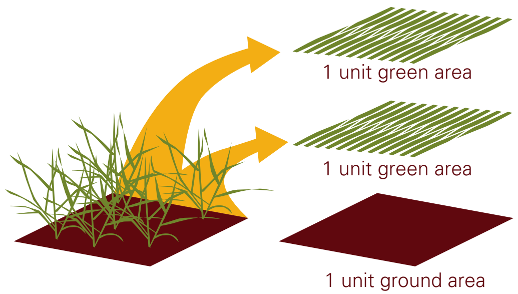


Illustration of GAI = 2 (two areas of green leaf and stem to one area of ground)



Glossary

Assimilate: The product of the crop's synthetic processes, mainly photosynthesis. Measured as dry matter.

Benchmark: A defined measure of crop progress consistent with good final performance.

Carbohydrates: Synthesised entirely from carbon dioxide and water, these are mainly starch and cellulose which are not 'soluble' or mobile, and sugars, eg fructan, which dissolve in water, are mobile in the plant and are classed as 'soluble'.

Coleoptile: The first leaf structure to emerge from the seed at germination. It protects the first true leaves during emergence of the seedling. It has little chlorophyll but may give rise to tillers.

Day degrees: see thermal time.

Dormancy: A condition in which grains do not germinate in the presence of adequate moisture, temperature and air.

Dry matter: Crop constituents other than water, left after tissue has been dried. Often, 'total dry matter' refers to just the above ground parts of the crop.

Dry matter is measured by weighing crop material after drying in a forced-draught oven at 80ºC until it reaches constant weight (for about a day).

Floret: The primary sub-component of a spikelet. Each floret can only bear one grain; whilst they retain this potential they are termed fertile florets.

Flowering: In wheat, flowering is normally recognised by appearance of pollen sacs (anthers) from florets within the ear. This signifies pollination. Flowering may also be called 'anthesis'.

Frost heave: Lifting of the soil surface, caused by freezing of moisture in the topsoil and expansion, often leading to stretching and breaking of roots and other sub-surface structures.

Fructan: A form of sugar, a polymer of fructose (the main component of soluble carbohydrate), used by wheat and other grass species as storage assimilate in stem tissues.

GAI: Green Area Index. The ratio between the total area of all green tissues, one side only, and the area of ground from which they came.

Hagberg falling number: A measure of the hot paste viscosity of a wholemeal suspension in water. In the laboratory a suspension of flour is heated in water for a fixed period. The time in seconds taken for a plunger to fall through the resultant gel is recorded as the 'Hagberg falling number'.

Harvest Index: the ratio between grain yield on a dry basis and the total crop dry weight at harvest.

Internode: The section of stem between two adjacent nodes.

Leaf blade: The upper portion of a leaf, from the tip to the ligule (junction with the sheath).

Leaf sheath: The basal portion of a leaf which encloses the stem and sheaths of younger leaves.

Ligule: A small structure at the junction of leaf sheath and leaf blade.

Lodging: Permanent displacement of a stem or stems from a vertical posture. Lodging can be considered as an event occurring within one day, although lodged stems may initially lean rather than lie horizontally.

Main shoot: The primary axis of the plant, on which the primary tillers are borne.

Mean: The average. The sum of all the values divided by the number of values.

Median: The middle value when all values are ranked by size. Medians may provide more robust summaries than *means* because they are not influenced by exceptional values.

N: Nitrogen.

Node: The point at which a leaf sheath is attached to a stem.

Partitioning: The division of dry matter between organs.

Peduncle: The topmost internode, between the flag leaf node and the base of the ear (the collar).

PGR: Plant growth regulator. The 'full PGR programme' used to grow the benchmark crops included chlormequat at the end of tillering and GS31, and Terpal at GS37-39.

Photosynthesis: Formation of carbohydrates by green tissues from absorbed carbon dioxide and water, driven by energy from sunlight.

Phyllochron: The interval in thermal time from emergence of one leaf tip on a shoot to emergence of the next. Phyllochron is the reciprocal of leaf emergence rate.

Pollination: Reception of pollen produced in the anthers and bearing the male genetic complement, by the stigma, leading to fertilisation of the ovum, bearing the female genetic complement. Fertilisation of wheat normally occurs within one floret, rather than between florets. (Flower parts are shown in a diagram on page 22).

Rachis: The portion of the stem within the ear (above the collar), bearing the spikelets.

Respiration: Degradation of sugars and the associated absorption of oxygen and emission of carbon dioxide (and water) to yield energy for crop metabolism.

Ripening: The changes that occur in the grain between completion of growth and maturity. These include drying, and development and loss of dormancy. Grain is considered 'ripe' when it is ready for harvest – at less than 20% moisture.

Senescence: Loss of greenness in photosynthetic tissues, normally brought about by ageing, but also by diseases or drought.

Shoots: All the axes of a plant with the potential to bear an ear. The main shoot and all tillers are included. Shoots retaining the potential to form grain are termed 'fertile shoots'.

Soil stability: The tendency for soil aggregates to retain their integrity when wetted and disturbed. It is measured by assessing how easily aggregates break up into fine particles.

Specific weight: or bulk density, is the weight of grain (corrected for variation in moisture content) when packed into a standard container. It is expressed in kilograms per hectolitre (100 litres).

Spikelet: the primary sub-component of the ear. About 20 spikelets are borne on alternate sides of the ear stem or 'rachis', and there is one 'terminal spikelet'. Each spikelet is contained within two glumes, and consists of several fertile florets.

Thermal time: The sum of all daily temperatures (mean of maximum and minimum) above a base temperature below which the process in question stops. In the case of leaf development this is 0ºC. Results are expressed in 'day degrees' (ºC days).

Tiller: A side shoot. Thus 'tillers' do not include the main- or primary shoot.

Transpiration: Loss of water vapour from a crop's green surfaces, mainly through leaf pores (stomata).

Vernalisation: A change in the physiological state of a plant from vegetative to reproductive brought about by a period of cold – can be applied to seeds or (in the case of wheat) to the young plant.

Vigour: Term used to describe the capacity of a seed, plant or organ to grow.

Waterlogging: Filling of soil pores with water to the extent that there is insufficient oxygen for normal root function.

Further information

HGCA publications (all available on the HGCA website)

HGCA Recommended Lists for cereals and oilseeds (annual)

Avoiding lodging in winter wheat – practical guidelines (2005)

The barley growth guide (2005)

Take-all in winter wheat – management guidelines (2006)

Topic Sheet 36 (2000) Optimum winter wheat plant population

Topic Sheet 40 (2000) Canopy management in winter wheat

Project Progress 8 (2002) Assessing risks to winter wheat plant population

Research Review 51 (2003) Factors affecting cereal establishment and its prediction

Project Report 151 (1998) Assessments of wheat growth to support its production and improvement

Project Report 234 (2000) Prediction of optimum plant population in winter wheat

Project Report 235 (2000) Reducing winter wheat production costs through crop intelligence information on variety and sowing dates, rotational position and canopy management in relation to drought and disease control

Project Report 257 (2001) Development and evaluation of a technique for the rapid measurement of cereal root systems

Project Report 292 (2002) Transferring new concepts into practice to improve the competitiveness of UK wheat producers

Project Report 351 (2004) Root system management in winter wheat: identifying practices to increase water and nitrogen use

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Websites

HGCA www.hgca.com

Wheat: the big picture. www.wheatbp.net

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